ROOF MAINTENANCE RECORD ANALYSIS TOWARD PROACTIVE MAINTENANCE POLICIES

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ROOF MAINTENANCE RECORD ANALYSIS TOWARD PROACTIVE MAINTENANCE POLICIES

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[To my mother & family who taught me to never give up]

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LIST OF ABBREVIATIONS

α*	=	Alpha Level
AIJ	=	Architectural Institute of Japan
ASCE	=	American Society of Civil Engineers
BELCAM	=	Building Envelope Life Cycle Asset Management
BIC	=	Bayesian Information Criteria
BUR	=	Built-Up Roof
BSE*	=	Backward Stepwise Elimination
C&S-R^2	=	Cox and Snell's R-Square
CDD	=	Cooling Degree Day
CERL	=	Construction Engineering Research Laboratories
CI*	=	Confidential Interval
CIB	=	International Council for Research and Innovation in Building and Construction
CMHC	=	Canada Mortgage and Housing Corporation
CMMS	=	Computer Maintenance Management System
COO	=	Cook's distance
CRMS	=	Computerized Roof Management Systems
DV	=	Dependent Variables
EPA	=	Environmental Protection Agency
EPDM	=	Ethylene Propylene Diene Monomer
EPV	=	Event Per Variable
ESL	=	Estimated Service Life
Exp B	=	Change in Odds
FM	=	Facility Management
FMECA	=	Failure Modes and Effects, and Criticality Analysis
FSS*	=	Forward Stepwise Selection
HDD	=	Heating Degree Day
HMDA*	=	Historical Maintenance Data Analysis
HVAC	=	Heating, Ventilation and Air Conditioning
IFCs	=	Industry Foundation Classes
IFMA	=	International Facilities Management Association
IRC	=	Institute of Research in Construction
ISO	=	International Organization for Standardization
IV	=	Independent Variables, Predictor Variables
NCDC	=	National Climatic Data Center
N-R^2	=	Negelkerke's R-square
NRCA	=	The National Roofing Contractors Association

NRCC	=	National Research Council of Canada
ORNL	=	Oak Ridge National Laboratory
PM	=	Preventive Maintenance
PMR	=	Protected Membrane Roofing
PVC	=	Poly Vinyl Chloride)
PWGSC	=	Public Works and Government Service Canada
RCA	=	Root Cause Analysis
RILEM	=	International Union of Laboratories and Experts in Construction Materials, Systems and Structures
ROC	=	Receiver Operating Characteristic
RPS	=	Real Property Services
RReDC	=	Renewable Resource Data Center
RSL	=	Reference Service Life
RSLP*	=	Roof Service Life Prediction
RTU	=	Roof Top Units
SE	=	Standard Error
SV*	=	Selected Variable
TFA*	=	The First Attempt (in factor method methodology-chapter 3 & 5)
TPO	=	Thermoplastic Polyolifin
TSA*	=	The Second Attempt (in factor method methodology-chapter 3 & 5)
TTA*	=	The Third Attempt (in factor method methodology-chapter 3 & 5)
USACERL	=	US Army Construction Engineering Research Laboratories
V	=	Cramer's V statistic
VIF	=	Variance Inflation Factor
VTR	=	Vent Through Roof
ZRE	=	Standard Residual for Dependent Variable

Note: '*' represents terms arbitrarily coined and used often in this research

SUMMARY

The objective of this study is to propose an approach that assists facility managers in obtaining the needed information to establish a proactive roof maintenance plan. Two main methodologies are used in this research. The first approach, Historical Maintenance Data Analysis (HMDA), investigates and pinpoints the root cause of roof leaks by thoroughly collecting and analyzing roof maintenance records. HMDA hypothesizes that a mathematical model can be developed to reveal relationships between potential roof leak causes and leak incidences. The second approach, Roof Service Life Prediction (RSLP), investigates the applicability of the 'Factor Method' in roof maintenance. The use of RSLP for leak predictions is based on the assumption that the first-time leak has a linear relationship with the estimated service life (ESL) of the roof.

This research demonstrates that roof maintenance records can be used to predict and identify major factors that are likely causes of roof leaks in a mathematical causal model. Roof leaks are not totally random events and can be predicted. In this study, three parameters (Age, Workmanship, and Roof Repair) have a significant impact on the roof leak's probability within the first three years of a roof's life. A unit change of workmanship and roof's age increases the odds of roof leaks. On the other hand, changes in roof repair decrease the odds of a roof leak. The 'Factor Method' performed in the RSLP confirms the existence of a relationship between the ESL and the first-time leak. The correlations discovered are positive and significant-to-highly-significant. The extents of correlation are found to be low-to-medium. The finding also illustrates a relatively simple and useful factor method technique that can be applied to the roof maintenance decision-making process.

The estimated service life of a roof provides a reasonable estimation of a maintenance-free period. When ESL information is used in conjunction with knowledge obtained from HMDA, the new synthesis of knowledge will expand the facility maintenance professional's ability to develop and schedule a proactive roof maintenance plan.

CHAPTER 1

INTRODUCTION

1.1 Background: Moisture Problems in Buildings

Moisture problems in building envelopes are common and universal. They affect all building types, geographical regions, and project delivery processes (Nevalainen, Partanen et al. 1998; Rao 2005). The problem can be found throughout North America and in the other parts of the world, including the Far East (Oliver 1997; Building Envelope Research 2003). For example, approximately three-quarters of all building damages registered in Norway result from water and moisture-related issues (Liso 2001), and over half of all building defects in the United Kingdom are caused by dampness (Oliver 1997).

Moisture-related problems in buildings are the subject of increasing public controversy and litigation. These problems have heightened public anxiety and caused concerns to building owners and users. Unwanted moisture, in the form of solid ice, liquid, or vapor, not only directly affects the physical make-up and functionality of buildings, but also inhabitants' health. Moisture accumulation causing bio-contamination in buildings is now a well-known key contributor in the spread of disease (Rivin 2001). The pervasive odors and low quality of indoor air are indicators and examples of moisture problems. Microbial growth in buildings has been associated with numerous mold-induced personal health problems, including bacterial, fungal and viral infection, allergic respiratory disease, humidifier fever, and atopic allergic and endotoxic/mycotoxic effects (Oliver 1997; Rivin 2001; Haverinen, Vahteristo et al. 2003).

Litigation related to water damages is also on the rise; a triple digit increase of lawsuits in commercial buildings has been observed (Rivin 2001; Smith 2002; Silicato 2003).

Limited public understanding of the link between mold exposure and health problems is arguably at the root of such an explosion of construction lawsuits (Rivin 2001; Silicato 2003). Legislators across the United States are also calling for more research, in order to develop guidelines and regulations to deal with such problems (Smith 2002).

Uncontrolled moisture causes visual, as well as physical damage, to buildings. Moisture accumulation can cause discoloration, staining, and blistering paint on building facades, and, in more severe cases, excessive moisture can compromise the building's structural and functional integrity through mechanical, chemical and biological degradation (Karagiozis 2003; Rao 2005). Damages caused by moisture include component disfiguration, dimensional changes, rotting, decay, mold, and corrosion. The unexpected deterioration can result in a shorter functional service life of building parts leading to the premature failure of the structure (CRDBER-1; IFMA 2003).

The economic consequences of building service failures caused by moisture are great, and water damages associated with building envelopes can be extensive and disruptive (Oliver 1997). Over the past decade, moisture-related damage costs have amounted to billions of dollars in North America alone (CRDBER-1; Karagiozis 2003; Rao 2005). Unwanted moisture in buildings can adversely effect and obstruct the intended use of buildings, especially in a damp-free required condition. In addition, accumulated water in building components can decrease building material's performance (Oliver 1997). The accumulation of moisture within a roof insulation lowers its efficiency up to a factor of three, causing greater heat loss (Wilson 1984; Time-saver Standards 2000; Karagiozis 2003).

Improving moisture control in the building envelope is now gaining tremendous interest from the academic field, as well as the building industry (Building Envelope

Research 2003). Many organizations have attempted to study different sources, causes and ways to prevent moisture build-up in buildings; the sample efforts are discussed later in this chapter.

1.2 The Research Problems

The research problem originates from facility managers' major concerns regarding sick building syndrome and other impacts from moisture-related problems. Recent studies have reported principal factors and conditions contributing to building mold growth (Rivin 2001; Rodriguez 2002). One conclusion is that indoor mold growth can only be controlled by managing moisture that enters facilities (Ricketts 1999; Rivin 2001; Agency 2003). This notion is similar to the recommendation from the U.S. Environmental Protection Agency (EPA). In general, moisture constantly enters a building though building envelopes in a variety of ways, depending on the moisture stage (liquid, vapor, or mixed state), and on transportation mechanisms. Therefore, to control moisture is to properly and effectively manage building envelopes.

Occasionally, dampness in buildings arises as a result of poor maintenance (Brand 1994). Building roofs, the single most-critical element in buildings (Bennett 1990; Griffin and Fricklas 1995; Oliver 1997; Patterson and Mehta 2001; Morcous and Rivard 2003; Hassanain, Froese et al. 2005), are constantly damaged from normal environmental wear and tear, and require regular maintenance. Nevertheless, in current practice, many building owners do not have roof or moisture management plans in place (Stern 2003). For some organizations, roof maintenance plans are proprietary, reactive, or too generic in nature. Many plans and schedules formulated for maintenance often fail due to the complexity and unpredictability of the environment (Cohen and Cohen 1983). Due to this, roofing-related decisions are typically made with incomplete information, and, therefore, approximately 85% of roofs are replaced unnecessarily (IFMA 2003).

Advanced information technology has been part of efforts in support of roof management. Several computerized roof management systems (CRMS) have also been developed to assist building owners in maintenance and replacement tasks. Many of these proposed concepts are generally embedded in a reactive paradigm where tasks are implemented based on the roof's current condition. Roof material performance testing in a controlled laboratory is also widely studied; however, these research efforts fail to consider the full complexity of the environmental influence on roof failure.

With ownership costs on the rise, building owners now realize that, only when effective tools are in place, the cost for maintenance will be reduced and service will be less disruptive (Arditi and Nawakorawit 1999a; Shohet, Puterman et al. 2002). Unlike human skin, roofs do not have a self-healing or continuous regeneration capability; therefore, the vigilance and scheduled preventive maintenance are the best solutions for a long life (Rivin 2001).

1.3 Study Scope

This research focuses on building roofs. Compared to other portions of building envelopes, roofs are much less durable, less energy-efficient, and more trouble-prone building components (Miller and Desjarlais; Wilson 1984). Water penetration through roofs, especially from rain and snow, is the largest, most-common source of unwanted water affecting buildings (Oliver 1997; Rao 2005) and is the major agent in this study. Water penetration causing envelope failure, in this context, refers to a process in which water enters a systems through an exposed surface, joint or opening (Beall 1999) and causes a loss of the envelope's main functions (loss of water tightness). Water tightness is defined by the ability to prevent of water leakage into buildings (Lounis, Vanier et al. 1998a)

Unlike material performance studies that try to explain the roof failure from the material durability standpoint, this research does not focus on or aim to use a physical principle-based degradation model to explain roof leak incidences. Rather, it employs the empirical technique using in-use data to try to explain the potential for roof leaks caused by human involvement.

Water intrusion caused by a movement of water in and through roof materials is not included in this study scope. This mechanism is generally known as the moisture transmission or transfer mechanism, and involves a variety of processes, such as absorption, evaporation, diffusion, osmosis, and capillarity (Oliver 1997).

The study is also limited to the low-slope roof with a single-ply roofing system, commonly used in non-residential buildings. The National Roofing Contractors Association (NRCA) annual survey reveals that, for the past five years, the single-ply membrane roofing system was used in approximately one-third of all installed roofs and is gaining ground in new construction projects. The study geography will cover the continental United States, with the exception of Alaska, Hawaii, and California. Two major components, skylights and HVAC units (Heat, Ventilation, and Air Conditioning), are also considered. These components are generally directly attached to the roof surface via roof curbs and can lead to water intrusion problems.

1.4 Research Objectives

The major goal of this research is to propose an approach to assist facility managers in obtaining the needed information to develop a proactive maintenance plan that can be applied to and/or increase the efficiency of the current building roofs maintenance practice. The goal of this research can be divided into the following objectives:

1. To inclusively explore and identify parameters potentially contributing to water penetration problems in building roofs using in-situ, historical roof maintenance data.
2. To define the impact of each parameter previously identified in (1) to roof leak incidences, and also predict the chance of roof leaks within the first three years of roof life using statistical analysis techniques.
3. To investigate the applicability of service life prediction methodology, specifically the 'Factor Method' technique in the roof maintenance domain.
4. Use knowledge gained to propose an approach to enhance or change the decision-making process regarding roof maintenance attitudes and plans.

1.5 Study Hypotheses

Two main hypotheses are defined as the following:

1. A mathematical model can be created from historical maintenance records to:
    1.1 Explain relationships of roof parameters and roof leaks; and
    1.2 Predict the increasing risk of roof failure in a particular roof assembly within the first three years.
2. The estimated service life derived from the 'Factor Method' concept proposed by ISO:

2.1 Is applicable to predict the estimated service of roofs for roof maintenance management purposes; and

2.2 Has a linear correlation with first-time leaks.

1.6 Research Outline

The following paragraphs outline the steps taken in this study to accomplish the research objective described in Section 1.4. Figure 1.1 lists these steps, along with the corresponding chapters in the dissertation.

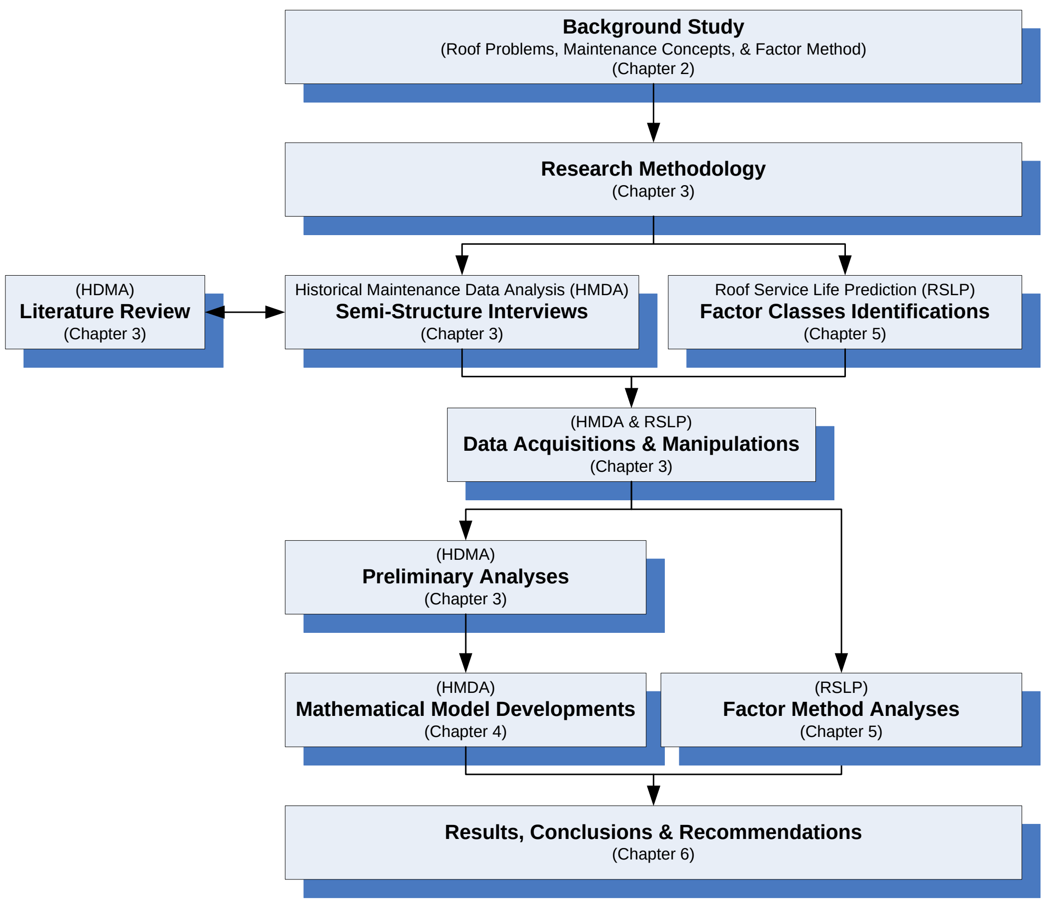

Figure 1.1 Study Outline

The outline of this thesis is as follows. Chapter 2 reviews building roofs, roof problems, and the concept of building maintenance. Different roof maintenance approaches and their related problems are investigated. Furthermore, a new service-life prediction method, the 'Factor Method' concept, is reviewed. Chapter 3 provides an overview of the research plan and problems experienced during the pilot research study. Two study approaches, Historical Maintenance Data Analysis (HMDA) and Roof Service Life Prediction (RSLP), are employed in this research. Results from the semi-structured interviews and the potential causes of roof leaks are described next in the chapter. Data acquisition, including sources and problems experienced during this process, are explained. The chapter finishes by presenting the preliminary data analysis. Chapter 4 provides a detailed explanation of the HMDA model development. A summary of the technique used, logistic regression analysis, is presented in the beginning of the chapter to provide an overview of the method. Problems encountered and solutions to each trial are presented. The chapter concludes with the model validation. Chapter 5 evaluates the applicability of 'Factor Method' in roof maintenance management. The chapter begins with the identification of each factor class according to 'Factor Method' principles in roof domain. Then, the relation analysis and results are presented. Chapter 6 presents and interprets the results from both study approaches. The chapter completes the thesis with discussion, conclusions, and an outlook towards future work.

1.7 Research Contributions

This research provides a systematic investigation of the root cause of premature roof failure and roof's service life to help facility managers better understand the risks associated with their roofs. General knowledge shows that the causes of premature roof failure are wide and various: how significant each factor and their interactions are to the problem is still an open question. Also, how long a roof will last remains a critical question for facility managers. This research contributes new knowledge to the study of premature roof failure by embracing the multi-factorial nature of the problem to model the causes of the problem; the 'Factor Method' provides an estimated service life of roofs and a potential timeframe of a first-leak occurrence.

By combining new knowledge gained from these two studies, a proactive roof maintenance management regime can be created. The findings also benefit the building industry as-a-whole, as industry personnel gain a better understanding of water penetration problems which were previously neglected and thought of as solely problematic during construction.

CHAPTER 2

LITERATURE REVIEW

2.1 Purpose

The purpose of this chapter is to review the existing literature to establish a point of departure for this research. The chapter is composed of three sections. The first part reviews general information and significance of building roofs. Roof problems and potential causes of roof leaks are described. The second section narrates the tools typically available to building owners to extend their built assets' lives. The building maintenance types and concepts are explained, and related problems to building/roof maintenance are also described. The chapter ends by describing a new proposed service-life planning concept and procedure that can potentially apply to roof management.

2.2 Building Envelopes: Roofs as an Important Part of Buildings

A roof functions as a durable, weatherproof and insulated cover for a building, and a roof system is one of the largest and most-important investments in a building (NRCA 2000). However, compared to other portions of building envelopes, roofs are much less durable, less energy efficient, and more trouble-prone building components (Miller and Desjarlais; Wilson 1984). Nearly 65% of all lawsuits brought against architects originate with roof problems (Patterson and Mehta 2001); Griffin and Fricklas claim that the numbers of lawsuits involving low-slope roofs systems equal or exceed the total number of lawsuits filed over all other building system combined (Griffin and Fricklas 1995).

Many researchers claim that the roof is the single-most critical element in buildings (Patterson and Mehta 2001). Despite this, roofs are considered unaesthetic and hidden components that usually receive less investment both from the construction and maintenance standpoint (Hassanain, Froese et al. 1999). Due to their function, roofs are exposed to more severe environmental factors than other building components. Roofs have to resist not only precipitation, but also snow, solar radiation, storm, and even human abuses. All of these mechanisms can lead to deterioration and, eventually, leaks. Still, roof defects are not easily recognized unless they reach critical conditions (Bennett 1990; Griffin and Fricklas 1995; Oliver 1997; Morcous and Rivard 2003).

2.3 Roof Components/Types/Systems

Roof systems and materials can be divided into two generic classifications: steep and low-slope roofing. A low-slope roof installs on a slope less than or equal to 3:12 (14 degrees), while a steep-slope roofs installs on a slope exceeding 14 degrees.

Pitched roofs consist of small, overlapping individual roofing units that employ the principle of water shedding. The slope must generate adequate gravitational force to move the water and to overcome wind, head pressure, and capillary forces that might push the water up the slope (Hardy 1998; Patterson and Mehta 2001).

Flat roofs are more popular in commercial buildings, due to the lower cost and greater ability to accommodate a large and complicated layout (Seeley 1987; Oliver 1997). A flat roof assembly uses a water tightness principle to prevent exterior water entering inside and is typically composed of three interrelated components: a roof membrane, insulation, and deck. Flat roofs can be distinguished by the position of the insulation within the roofing system assembly. There are exposed (conventional) membrane roofing systems, in which the rigid insulation is below the roofing membrane, and protected (inverted) membrane roofing (PMR) systems, where the insulation is above the roofing membrane (Hassanain, Froese et al. 1999). Various materials used on each roof system can be seen in Figure 2.1.

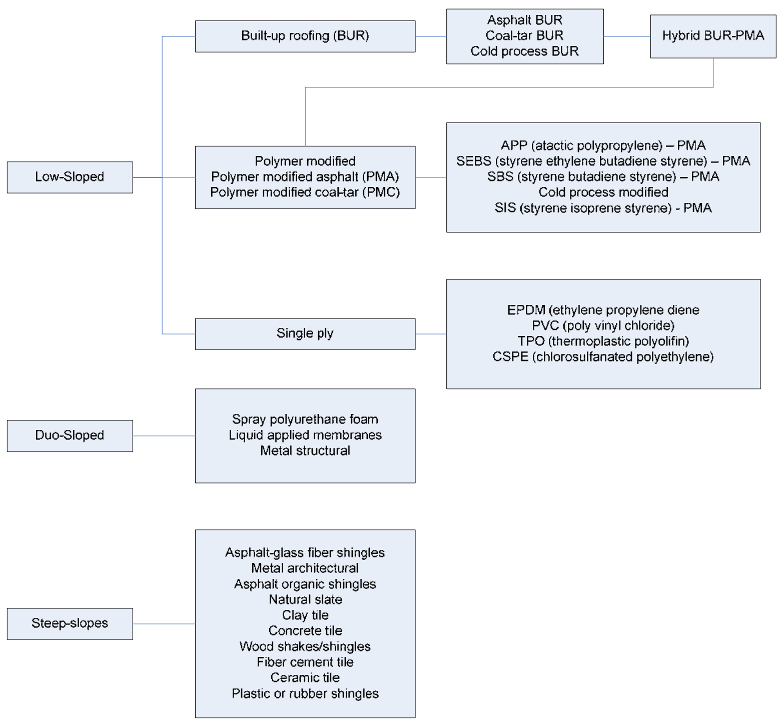

Figure 2.1 Roofing System Classification (Cash 2003)

According to the National Roofing Contractors Association (NRCA), five generic classifications of low-slope roof membranes/systems are currently available in the market (Wiseman 1998; NRCA 2000):

1. Built-Up (BUR) Membranes; Asphaltic or Coal-Tar
2. Metal Panel
3. Polymer-Modified Bitumen Sheet Membranes; APP or SBS

4. Single-Ply Membranes; Thermoplatic or Thermoset

5. Spray Polyurethane Foam-Based (SPF) Systems

This study places an emphasis on the traditional system, in which the roof covering material is a single-ply membrane with mechanical fastening.

2.3.1 Single-ply Membranes (NRCA 2000)

Single-ply roof membranes are factory-manufactured sheet membranes. They may contain reinforcement layers, polyester fabrics (scrims), glass fiber, or felt or fleece backing. The finished sheet's thicknesses typically range from 30 to 60 millimeters (1 millimeter equal to 0.001 inch). Single-ply membranes can be fully adhered, mechanically attached, ballasted, protected membranes roof assembled, or can combine different attachment techniques to secure a roof system. In general, single-ply membranes are classified as:

1. *Thermoplastic*: Thermoplastic materials have no chemical cross-linking, a major difference from thermoset; therefore, they can be repeatedly softened when heated and hardened when cooled. Thermoplastic membranes are typically seamed by heat welding with hot air or solvent weld. Five common subcategories of thermoplastic membranes are: 1) Polyvinyl Chloride (PVC); 2) PVC Alloys or Compounded Thermoplastics; 3) Chlorinated Polyethylene (CPE); 4) Polyisobutylene (PIB); and 5) Thermoplastic Olefin (TPO).

2 *Thermoset*: Thermoset principal polymers are chemically cross-linked (vulcanized or cured); therefore, a material is irreversibly solidified after heating. No new molecular linking can be formed once thermoset polymers are cured; they only can be bonded to like materials with an adhesive. Four common subcategories of thermoset roof membranes are:

1) Chlorosulfonated Polyethylene (CSPE); 2) Ethylene Propylene Diene Monomer (EPDM); 3) Epichlorohydrin (ECH); and 4) Neoprene (CR).

2.4 Building/Roof Problems: Leaks

2.4.1 Water Sources and Transportation Mechanisms

Next to the structural adequacy, water exclusion is probably the most-important technical performance indicator and crucial requirement of any building (Oliver 1997). However, there is still a need to understand how to make a building watertight and exactly how building assemblies leak (Oliver 1997).

Dampness occurs when excessive water is presented and can have numerous adverse effects on buildings (Brand 1994). Most dampness cases usually come from one or a combination of condensation, rising damp, and penetrating damp (Oliver 1997). Water penetration, especially from rain and snow, is the largest, most-common and significant (Oliver 1997; Rao 2005); therefore, it is the focus of this study. Water penetration, in this context, refers to a process in which water enters a systems through an exposed surface, joint or opening (Beall 1999). Penetration dampness can be seen in the form of frozen or liquid precipitation entering building envelopes through defects (Nevalainen, Partanen et al. 1998; Rivin 2001).

Pressure differential can cause penetrating damp to enter a building both vertically or horizontally, and is the key agent responsible for all building leaks (Botsai qtd. in Oliver 1997). It can pull or suck water in and is the most-critical factor in creating pressure on horizontal surfaces (roofs) (Wilson 1984). Several sources of pressure differential causing unwanted water to enter building are identified; however, the four predominant are: Natural

Gravity; Surface Tension; Wind/Air Currents; and Capillary Action (Oliver 1997; Kubal 2000). Each of these mechanisms can act independently or in combination with other factors.

Gravity can move water from the exterior surface, and is a predominant force of water entering on horizontal planes where weak-points in the waterproofing barrier exist. Capillarity action, on the other hand, can not only move water and redistribute within building envelopes, but it can also create surface tension forces (Lstiburek and Carmody 1991; Oliver 1997; Kubal 2000). Wind load has a capacity to push water vertically, and the only time the horizontal membranes are affected by wind load pressure is when the integrity of flashing is involved (Kubal 2000).

Typically, roof leaks occur when the following three conditions exist: 1) presence of water (groundwater or rain); 2) an opening or hole in the roof components; and 3) a driving force (gravity and/or pressure differential) (Wilson 1984; Lstiburek and Carmody 1991; Time-saver Standards 2000). For rain to enter a building, a vehicle to carry it through apertures, such as holes, crack, or gaps, must exist; in this context, the air is generally the vehicle for water. Against common perception, Botsai claims that the velocity of water or wind striking the building's surface does not cause leaks; rather, the pressure differential between inside and outside is the cause (Wilson 1984). Humans cannot control any of these, but may be able to influence the magnitude of these forces.

2.4.2 Potential Causes of Roof Leaks from Humans

The cause of roof problems involving humans obviously cannot be attributed to any particular stage of roof life, but is interwoven among choices of design, installation and maintenance, the 90%/1% principle (Kubal 2000). There remains a need to improve construction methods, quality control, and workmanship, as well as for the design community to improve its understanding of the processes involved. The research community also needs to provide proper design guidelines to avoid these problems in the future (Rao 2005). Generally, problems related to design or construction inadequacies or omissions take a long period of time to notice and are very difficult to diagnose and correct (Nevalainen, Partanen et al. 1998; Rivin 2001).

Most roofs are not installed under factory control conditions and, as a consequence, roofs experience a variety of inherent imperfections (Oliver 1997; Rivin 2001). Some premature roof failures are attributed to economic and technical factors (Griffin and Fricklas 1995). Budget constraints limit the owner/designer's freedom in choosing the appropriate roofing system for a specific building, resulting in premature roof failures. Many owners have learned the hard way that initial cost should not always be the determining factor in selecting a roof system (Herbert 1989).

New roof materials inundating the market may also be responsible for roof problems. Although roofing products are generally subjected to several laboratory tests before being introduced to the market, none of these tests can fully simulate the actual field conditions. It will take several years to identify a suitable use of a new roofing product for a particular climatic region (Brand 1994).

Newly introduced roof materials can also result in incorrect application of new materials and techniques (Brand 1994; Griffin and Fricklas 1995). According to the National Roofing Contractors Associations (NRCA) manual published in 2000, there were 185 low-slope material manufacturers of over 1,500 products and more than 2,000 roof system specifications. Choosing the right roofing product and specification can be a daunting task. A lack of experience with new roof materials, when combined with a lack of performance-based data, can complicate roof design and lead to roof failure (Griffin and Fricklas 1995; Patterson and Mehta 2001). The quality of roof materials, however, is generally not the culprit of roof leaks (Kubal 2000). Kubal claims that approximately 99 percent of water proofing leaks are attributable to causes other than material or system failures (Kubal 2000). The finding agrees with the majority of opinions from the roof experts interviews conducted in this study.

Roof failure can also result from lack of training on new installation techniques (Patterson and Mehta 2001). Different parts of the country have their own regional roofing practices, and these procedures often vary and are dictated by climatic conditions, material availability, and time-proven area practices (Scharff 1995). These scenarios are examples of technical problems that lead to premature roof failures.

During the design process, the focus is on building aesthetics and cost, rather than performance. Often times, the concept of an integrated building's envelope components acting as one system and the interactions between roofs, other building systems, and environmental forces are ignored (Lstiburek 2002). A synergy of certain types of buildings, building design, construction methods, or building practices results in certain types of building problems (Nevalainen, Partanen et al. 1998). Differences in materials and environmental forces can result in: 1) different ways in which buildings respond; 2) the way in which problems manifest themselves; 3) the time frame in which failures occur; 4) the way in which problems are investigated; and 5) the extent and nature of repairs required (RDH Building Engineering Limited 2001). Regardless of the type of roof system or covering used, it is generally agreed that a good roof system requires proper design, quality materials, quality application, regular inspections, and proper maintenance (Kubal 2000; NRCA 2000; Kennedy 2001).

All projections through roofs initiated during a design phase can also be regarded as the sources of potential weak-points. A bunch of projections can increase the chance of inadequate flashing and sealant application, which is critical for the roof's water tightness integrity (Oliver 1997). In most roofs, flashings are considered to be the most-common source of roof leaks (Griffin and Fricklas 1995).

Occasionally, dampness in building arises as a result of poor maintenance (Brand 1994). Undetected entrapped moisture in the roof has been labeled as the number one contributing factor for premature failure (IFMA 2003). The roof membrane is constantly damaged from normal environmental wear and tear, and requires regular maintenance. Unlike human skin, roofs do not have self-healing or continuous regeneration capability; the vigilance and scheduled preventive maintenance are the best solution for a long life (Rivin 2001).

2.5 Building Maintenance Functions

2.5.1 Concepts of Building Maintenance

Maintenance and repair, one of the building maintenance and operations subtasks (Cotts 1998), is based on the concept that there are benefits in taking care of built assets to avoid suffering from a malfunction.

All built assets gradually loose their performance ability from the time of installation, though at differing speeds. The deterioration rate typically depends on materials, construction means and methods, usage, climatic effects, or geographic conditions. Ideally, the required maintenance tasks begin at the same time the building is built and carries on throughout the building's life. This task can, in theory, optimize expenditures and maximize facilities' value. The maintenance plan is typically based on the fundamental aims and objectives of the organization that owns or occupies the building (Arditi and Nawakorawit 1999b; Vanier 2001). Some organizations plan to temporarily occupy a facility; while others intend to stay in the same building for a long period of time.

A maintenance program is necessary for numerous reasons. Basically, maintenance work can and will increase the life of a building and its support systems. The study of IBM buildings in the United Kingdom confirms that even poor maintenance can prevent premature failures of some building components (Kincaid 1994). Building maintenance helps ensure safety and sanitary conditions of building's occupants, as well as continuously meet the designed functions (Wireman 1998). Maintenance also helps make the building acceptable for sociological and psychological reasons.

2.5.2. Types of Maintenance

Building maintenance can be classified as "planned" and "unplanned", according to the BS 3811, as shown in Figure 2.2 (Seeley 1987). Planned maintenance is organized and carried out with forethought, while unplanned maintenance is performed on an as-needed basis. Building maintenance can also be categorized as "predictable" and "avoidable". While predictable maintenance is similar to planned maintenance, avoidable maintenance is to rectify failures caused by poor design, faulty materials, or incorrect installation.

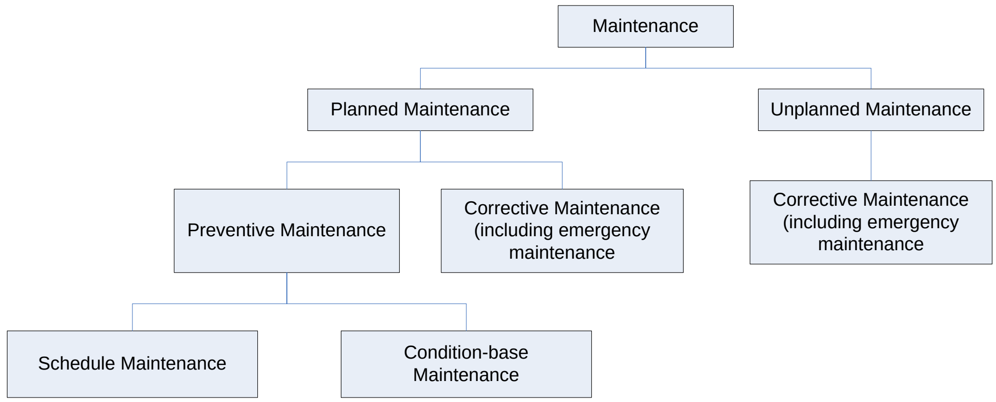

Figure 2.2 Types of Maintenance (Source: BS 3811: 1984 qtd in Seeley 1987)

Maintenance tasks can be subdivided further, based on the maintenance means or resources required to performed the work (Magee 1998), or grouped into boarder categories, such as major repair, periodic maintenance, and routine maintenance (Seeley 1987). Cotts claims that the numerous maintenance strategies can be classified into one of six general categories below (Seeley 1987; Kaiser 1989; Cotts 1998; Magee 1998; Wireman 1998):

1. *Inspect and Repair Only As Necessary*: The work is intended to restore an item to a required function performance state after a failure has occurred.

2. *Breakdown/Emergency Maintenance*: It is an unplanned work that needs immediate attention to avoid serious consequences.

3. *Cyclical/Routine Maintenance*: Scheduled work performed at a pre-determined interval of time, numbers of operations, mileage, etc., or a request of a non-emergency nature to restore a system to its original capacity (Vanier 2001).

4. *Preventive Maintenance (PM)*: This is a planned and controlled program involving a periodic inspection, test, and analysis for potential breakdowns, in order to reduce the potential premature failure of an item.

5. *Predictive Maintenance*: Involves monitoring the component performances to detect any signs leading to a failure. The goal is to ensure that any impeding failure is detected before it occurs. Once detected, the wear component will be tracked closely and a replacement is scheduled before it fails during an operation (Wireman 1998).

6. *Replace/Revamp/Renovate/Modification*: Involves repair/replace projects that arise as a result of the end of the components' service life.

Anderson proposed that maintenance concepts can be classified into six different schools of thought as follows (Anderson 2001):

1. *The Process School*: This school considers maintenance as a series of processes that can be modeled based on various aspects of maintenance management. The defined model is then used to: audit the maintenance process; teach the maintenance theory; and research to improve maintenance process. An example of process school is Production Control.

2. *The Mathematical School*: This school approach is to define and express the maintenance problem in the form of a mathematical relationship. Typically, this school is concerned with finding a quantitative solution, especially economic optimization, to maintenance management problems. An example of process school is Operational Research Theory.

3. *The Reliability School*: The Reliability School focuses its maintenance strategies on items that tend to cause problems. The maintenance plan is a result of the component's prior analysis (before the event) to avoid perceived mandatory or economic failure consequences. Some examples of reliability maintenance are Reliability Centered Maintenance (RCM), Failure Modes and Effects, and Criticality Analysis (FMECA).

4. *The Quality School*: This school is heavily influenced by the Deming cycle paradigm (Plan-Do-Check-Act) and aims to ensure the highest quality product/service with limited waste. Some examples of this school are Total Product Maintenance (TPM), Total Quality Maintenance (TQMain), and Situational Maintenance (Riis, Luxhoj et al. 1997) .

5 *The Condition-Based School*: The school objectives are to identify and measure parameters that can detect the beginning of failures. Examples of condition-based maintenance processes are Predictive Maintenance or Just-in-Time maintenance.

6. *The Work Management School*: This school regards maintenance management as a process of planning, organizing, and controlling maintenance work. These processes include preparing, producing schedules, allocating work, and measuring. An example of the Work Management School is Computer Maintenance Management System (CMMS).

2.5.3 Building Maintenance Management: Needs and Problems

The maintenance and repair of the built environment presents a major and rapidly growing cost. In some organizations, maintenance is the largest single controllable expenditure and, often times, exceeds their annual net profit (Fitch 1992; Al-Hammad and Assaf 1997). Based on a conservative estimation, the maintenance and repair expenditure per year in U.S. alone may be as high as $500 billion (Vanier 2001).

In addition to the growing cost of maintenance, a more-sophisticated design also increases the need for effective building maintenance management (Arditi and Nawakorawit 1999a). Many building owners understand that a purely reactive maintenance approach is not in their best interests. They realize that only when reliable data and effective tools are in place, the cost for maintenance will be reduced and service will be less disruptive (Arditi and Nawakorawit 1999a; Shohet, Puterman et al. 2002).

In the past three decades, new construction projects have gotten the lion's share of attention; as a result, many organizations sometimes end up with more facilities than they can afford to maintain (Sawers 2000). The strategic relevance to facility management, however, often times are not deemed a matter of serious concern or a high-priority item in designing and managing buildings (Arditi and Nawakorawit 1999a; Barrett and Baldry 2003). Facility management tasks are generally considered by many companies to be a purely operational function and exist solely to provide a day-to-day service (Sherwin 2000; Barrett and Baldry 2003). Even in the facility management department itself, it may be difficult to introduce the concept of preventive maintenance to crews who have a corrective mindset attitude (Barber and Hilberg 1995).

In many organizations, the way the facility is managed does not match with functional and physical needs of most built assets (Jones-Crabtree 2001). The problems are caused by two factors – insufficient funding, and the lack of crucial maintenance information. The inability to define needed budgets, due to this lack of information, leads to inappropriate funding being received. In turn, this funding shortfall makes proper planning difficult. When not enough attention and funds are spent on maintenance and repair, building owners experience an accumulation maintenance deficit or negligence, or facilities that receive only remedial treatment. These conditions will eventually lead to premature deterioration (Sawers 2000; Vanier 2001). The accumulation of maintenance deficit is reflected in an increase of deferred maintenance. In 1991, the deferred maintenance backlog of U.S. colleges and universities was reported to be $60 billion, which represented 20% of the replacement value (Sawers 2000).

The benefit of preventative facility maintenance and repairs is less tangible (Arditi and Messiha 1996; Ottoman, Nixon et al. 1999). Therefore, facility owners frequently keep maintenance expenditures to a minimum, even though the needed funds already exceed the budget available to them (Morcous and Rivard 2003). Such policy ignores or misunderstands the adverse long-term effects on the facility (Seeley 1987). In a current situation, building owners are challenged from all sides ranging from fiscal constraint to increasing repair backlog, which makes maintenance tasks seem even harder to manage (Vanier, Lacasse et al. 1997; Jones-Crabtree 2001; Vanier 2001).

In a situation where a budget is tight, facility management teams have to make a difficult decision whether to spend limited funds on particular components or defer the maintenance. If the maintenance is selected, then components and the proper intervention plan to extend a facility's life at the least-possible cost need to be considered. In general, the interval between preventive maintenance actions on a particular component is established by the individual manufacturer, and empirical measurements of degrading performance in facility maintenance records (Magee 1998). A survey study found that the recommended preventive maintenance schedules from manufacturers are excessive and receive less degree of confidence or enthusiasm from practitioners (Barber and Hilberg 1995).

The lack of understanding of facility maintenance not only wastes valuable information that can be utilized for facility improvement, but also increase an inefficient or inappropriate use of scare resources (Vanier 2001; Barrett and Baldry 2003). The lack of understanding, on one hand, causes building owners to spend billions of unnecessary dollars each year on excessive maintenance and replacement components for their buildings. On the other hand, some organizations let buildings deteriorate into a state from which it is very difficult and costly to recover (Arditi and Nawakorawit 1999a).

Currently, numerous equipment and building maintenance management strategies proposed by academic, industrial practitioners, and consultants are overwhelming the industry. This phenomenon has created a situation that causes confusion and conflict for people who are caught in the "Maintenance Theory Jungle" (Anderson 2001). One of the jungles is semantics or terminology, in which definitions of certain words or terms lack universal recognition. A lack of a universal terminology is exacerbated by a lack of a structured body of knowledge in maintenance management. This situation leads to a conflict between schools of thoughts that try to fill the body of knowledge, and, thus, leads to an increase of customized maintenance management styles. Cooperation from industry, academic institutions and maintenance societies to identify a body of knowledge and universal accepted terms is required to untangle this jungle (Anderson 2001).

Building roofs, similar to other building components, also experience insufficient funding and lack of crucial maintenance information. During the operating and maintenance stage, many building owners do not have roof management in place (Stern 2003). For example, in the "Public Buildings Maintenance Guides and Time Standards" manual for the General Services Administration (GSA), the largest landlord in the United States, only a few sections mention procedures regarding building envelope preventive maintenance. The U.S. Army, which owns more than 300 million square foot of roofs, has long struggled in managing their roof inventory to make the best use of their limited maintenance (Bailey, Brotherson et al. 1993). Due to a lack of crucial tool and information, roofing-related decisions are typically made with incomplete information and roofs are replaced unnecessarily (IFMA 2003)

For organizations where periodic building envelope inspection is implemented, the procedures are proprietary. Generally, visual surface observation on roofs is a standard procedure; only when problems are extensive, a conditional assessment and evaluation, either non-destructive or destructive, will be performed. These techniques are reactive in their nature. The visual inspection cannot reveal existing subsurface defects and can lead to inaccurate diagnosis and continued deterioration. The latter, condition assessment method, is usually performed when problems have obviously severely damaged building's components, and generally takes an owner a longer time to realize the problem (Stern 2003).

Deferred roof maintenance is also a typical problem in roof management which results in a reduction of building performance (Sawers 2000). The lack of qualified roofing staffs (roofers) to regularly monitor roof conditions and inattention to maintenance are two main reasons (Kennedy 2001).

Premature roof failures due to lack of proper maintenance are common (Lounis, Vanier et al. 1998a), and the associated costs of repair can be a substantial portion of the yearly maintenance budget. According to the General Office Audit of Canada, the conservative estimate for roof repair is 30 to 35 percent of all annual repair expenditures (Lounis, Vanier et al. 1998a). Eighty-percent of building envelope failures appear within the first year after construction, and 90% of them become visible in the first two years after construction (Shohet, Puterman et al. 2002).

2.5.4 How the Industry Deals with Roof Maintenance

Advanced information technology has been part of efforts in support of roof management. The expert system concept is frequently used to develop such systems. For example, LEAK FREE (Local Evaluation and knowledge for Roof External Expertise) is an expert system used for supporting the maintenance of built-up and modified bituminous roofing systems (Morcous and Rivard 2003). ROOF, a rule-based expert system, assesses the durability of flat roofs. The system diagnoses roof defects that can affect flat roofs using over 1,000 rules to predict roof service life (Saunders and Goodier 1999). SEDAR (Support Environment for Design and Review) is a graphic expert system used during the design and revision process of low-slope roofs (Morcous and Rivard 2003).

Several computerized roof management systems (CRMS) have also been developed to assist building owners in maintenance and replacement tasks. Some examples of these packages are CAMP-Roofing Management Program, REVS-Roofing evaluation System, Micro ROOFER, ROOFWORKS, InfoROOF Professional, and RoofManager. According to the study by Morcous and Rivard, MicroROOFER, an automated part of the ROOFER engineered management system, performs better than other systems (Morcous and Rivard 2003).

The ROOFER, an engineering management system, is a decision-support tool developed by the U.S. Army Construction Engineering Research Laboratories (USACERL). It applies repeatable inspection procedures and standardized analytical methods to calculate overall components' condition indexes, in order to develop repair strategies and establish planning and budgeting needs. The automated component, MicroROOFER, is a database that stores roof distress information and calculates the overall condition index that is needed for effective network management. The overall roof condition index is generally derived from the combination condition index of three major roof's components: membrane, flashing, and insulation based on visual inspection (Cash and Bailey 1993; Bailey, Cash et al. 2002).

Additional research efforts have also been led by industry groups. The Canada Mortgage and Housing Corporation (CMHC) conducted a benchmark study to determine sources of building moisture and recommended solutions to prevent moisture build-up in its CMHC's "Best Practice Guides." This guideline, however, focuses on residential structures with steep-slope roofs. The Oak Ridge National Laboratory (ORNL) has developed an advanced hygrothermal and damage model, WUFI-ORNL/IBP, to predict envelope responses to different climate conditions. These efforts focus on the effect of moisture on building envelope materials performance. Some strategies to control moisture transport into buildings are presented in Listiburek and Camody's "Moisture Handbook". The authors suggest that waterproofing and weatherproofing of roofs are dependent on choosing the appropriate systems and choice of materials (Lstiburek and Carmody 1991).

The Building Envelope Life Cycle Asset Management (BELCAM) project, funded by the Institute of Research in Construction (IRC) of the National Research Council of Canada (NRCC) and the Real Property Services (RPS) branch of Public Works and Government Service Canada (PWGSC), attempts to use technology-based tools to help building owners make a cost-effective maintenance decision. The initial application domain of this project is low-slope roofing systems, and a number of research works have been proposed under this project. For example, Morcous and Rivard's work focuses on solving the limitations of on-the-shelf, ready-to-use computerized roof management systems (CRMSs). They claim that the current CRMSs lack the ability to represent roof data at different manageable levels and accurately predict the service life of various roof components. A new proposed CRMS uses an object-oriented conceptual model and case-based reasoning to predict the future condition of roof components based on the recorded condition of similar components. Morcous and Rivard claim that case-based reasoning can provide a more-accurate remaining service life prediction due to its use of in-situ data of similar cases.

Lounis, Vanier, and Lancasse, a part of the BELCAM project, used stochastic modeling technique to predict the incremental deteriorations of roof components. This probabilistic model, coupled with an optimization algorithm, is used to develop a risk-based optimal roof maintenance management system. This approach takes into an account the uncertainty and variability associated with material properties, environment degradation factors, quality of workmanship, and maintenance conditions (Lounis, Vanier et al. 1998a).

Another approach is to use the life-cycle asset management model to manage building components, including roofs. The proposed model assesses and indexes components' current and desired future conditions. The maintenance task is then prioritized and carried out based on the conditioned index. This technique is suitable for a facility with a limited budget and similar to the method used in MicroROOFER (Sawers 2000).

The other approach to maintain roofs focuses on capturing and reusing data. The object model for roof maintenance management, built upon the Industry Foundation Classes (IFCs), is proposed. The model represents the possibility of increasing the efficiency of roof maintenance management by exchanging and sharing maintenance information between computer applications and the individual (Hassanain, Froese et al. 2000).

On the other end of the spectrum, Construction Engineering Research Laboratories (CERL) has embarked on a series of research studies focused on material performance in order to predict the durability of roofing materials. Twelve different roofing membranes in four different climates and laboratories are tested (Cash, Bailey et al. 2005). The studies center on characterizing roofing materials based on in-service performance requirements and identifying degradation factors and mechanisms that can be used in accelerating aging tests for service-life prediction (Cash and Bailey 1993; Bailey, Cash et al. 2002; Cash, Bailey et al. 2005). The changing of compositions and introduction of new materials leading to an unknown long-term durability are the inspiration of the study. One of the study's conclusions is a predictive service life test should be based on physical and chemical degradation measured after accelerated adding tests in different climate zones (Cash and Bailey 1993).

As described above, the efforts to improve roof maintenance management are either on testing material performance, or proposing new ways to manage roofs. However, many of the proposed concepts are embedded in a reactive paradigm where tasks are implemented based on the roof's current condition. The problems must be detected first in order for maintenance plans to be created. To produce a reliable and effective maintenance plan, the facility management team needs to make best-informed decisions and predict the service life of the component from the beginning of roof life (ISO 2000; Shohet and Paciuk 2006). A new roof maintenance approach is needed in order to change the current roof maintenance management attitude.

2.5.5 Proactive Maintenance Concept

A new paradigm "Proactive Maintenance" has now received a world-wide attention as a means of achieving saving surpassed by conventional maintenance technique. The proactive maintenance practice is a response to a failed reactive maintenance philosophy and aims at failure root causes, not just situational symptoms (Fitch 1992).

Root Cause Analysis (RCA) is a problem-solving method aimed at investigating, identifying, and eliminating failure at the source. Along with improving staff's attitude and competency, the RCA can increase component's intrinsic reliability (Narayan 1998). Root Cause Analysis is generally a collective term used to describe a wide range of approaches, tools, and techniques used to uncover causes to problems. Some sample tools are structured analysis techniques, such as: fishbone; stair-step; event-tree and fault-tree analysis; 5 whys; Pareto Analysis; Failure Mode; Effects Analysis; and Causal Factor Analysis (Wikipedia 2007). Each approach has a different aim, some geared toward identifying the true root causes while others are more general problem-solving techniques (Andersen and Fagerhaug 2000).

Service-life planning is concerned with foreseeable risks of degradation and maintenance; it is a major counter strategy to the reactive maintenance management that many roof CRMS cannot fulfill (Morcous and Rivard 2003). The service-life prediction process aims to develop methodologies that allow effective rational maintenance management of buildings regarding physical durability and life-cycle costing (Gaspar and de Brito 2005). By knowing how long each part of the building will last, the designer/owner can design the specification and details, including maintenance planning, which eventually reduces cost of ownership. Equipped with factors that contribute most to roof problem knowledge, the service-life prediction planning can potentially improve and change the way facility managers manage their built assets.

2.6 Service-Life-Prediction Methods

Two approaches widely used to estimate service life are accelerated aging tests and field data surveys. The former technique provides the researcher an in-depth understanding of the degradation mechanisms that lead to a loss of the buildings or element performance in a scientifically controlled environment (Morcous and Rivard 2003). The latter uses collected on-site data to assess the degradation level and overall element conditions.

The age accelerated approach, although widely adopted, has often been questioned by many researchers, since it fails to consider the full complexity of the environmental context. The field survey also regularly suffers from unreliable data from a statistical point-of-view. The uniqueness of each built asset and sometimes a lack of needed data are attributed to a small number of samples with similar characteristics (Saunders and Goodier 1999). In addition, buildings and their components have several degradation patterns that need to be identified independently, as opposed to one universal pattern (Gaspar and de Brito 2005). For the past 10 years, national standards have been developed to assess the expected service life of building materials and constructed facilities (Rudbeck 1999). However, no reliable quantitative method of service-life prediction has gained wide-spread acceptance (Wolf 2003).

The new service-life prediction method purposed by the International Organization for Standardization (ISO), the 'Factor Method', aims to be generic and to produce a reliable service-life estimation using all available data. The forecasting objective is to establish whether the design system can be expected to exceed the required design life with adequate reliability. This method considers the inherent characteristic of each building element and agent that causes degradation (Shohet, Puterman et al. 2002; Gaspar and de Brito 2005).

2.6.1 What is 'Factor Method'?

The International Organization for Standardization (ISO) 15686 proposed 'Factor Method' to forecast the service life and estimate the timing of necessary maintenance and replacement of components (Marteinsson 2003). This method is based on the "Principal Guide for Service Life Planning of Buildings: 1993", developed by Architectural Institute of Japan (AIJ) and the work of CIB, RILEM, and standards published in UK, Canada, and the U.S. The 'Factor Method' allows an estimate of the service life to be made for a particular component or assembly in specific conditions. It estimates the life of components by adjusting the reference service life with a modified factor that relates to the specific conditions of the case. ISO 15686-1, 8.2 proposes the following seven factors to account for difference between the object-specific and in-use conditions (ISO 2000; ISO 2006), as shown in Figure 2.4. The explanation of each factor can be seen in the Appendix A.

Factor Class A:	Inherent performance level (previously called Quality of components)
Factor Class B:	Design Level
Factor Class C:	Work Execution Level
Factor Class D:	Indoor Environment
Factor Class E:	Outdoor Environment
Factor Class F:	Usage Condition (previously called In-Use Conditions)
Factor Class G:	Maintenance Level

Figure 2.4 Factor Classes of the Factor Method

Any one or a combination of these factor classes can affect the service life. Due to relative newness of the field, many factors affecting the performance/life of even traditional components are not fully understood or researched. The factor class values are, therefore, typically up to the user to set or find (ISO 2006). The factor value can be set from: experience; known actions of the environment on specific materials; manufacturers; results of testing; and feedback from practice through condition assessment. However, the critical properties deemed to degrade in the object-specific in-use condition need to be encompassed (ISO 2006). The output of the service-life planning is a series of predicted service life of components, and a projection of maintenance and replacement needs and timings.

The 'Factor Method' is applicable to use as a guide for all prediction process in either new or existing buildings. In the latter case, the assessment aims to identify residual service life of the items that are already installed. As 'Factor Method' employs an empirical means, it is not as precise as other scientific methods based on observation over time or modeling of performance (ISO 2000).

The term 'predicted service life' in ISO 15686 typically means a forecast service life derived from laboratory tests, as described in detail in ISO 15686-2: Service Life Prediction Procedures. The result from this process is generally used as a reference service life (RSL). The reference life is defined as service life that a building or parts of a building would expect in a certain set (reference set) of in-use conditions. The reference life can be derived from manufacturer literature, results of testing, and feedback from practice (ISO 2000). However, if another source of information is used to provide the RSL and the procedure involves adjusting factors to reflect project specific factors, it is then referred to as the 'estimated service life'.

When quantitative information is lacking, a grading of the in-use conditions within that factor class can be made. The in-use condition grade is, however, not the same as the value of the corresponding factor; it is a way to quantify qualitative information and use for estimating the value of each factor. The qualitative information should be valued and interpreted to correspond to the in-use condition grade 1 to 5, as presented in Table 2.1.

Table 2.1 Options of Grading In-Use Conditions of Factor Classes A, B, C, F, and G (ISO 2006)

Grade	Description	Comments
0	Not available	Should never be applied to factor A
1	Very high/mild	
2	High/mild	
3	Normal	
4	Low/severe	
5	Very low/severe	
NA	Not applicable	Should not normally be applied

Not all components, however, need to be estimated; the decision to use 'Factor Method' is typically based on the critical use and cost of the building/component agreed by the project team and owner. Also, not all the information for the seven factors has to be available for the estimation. Any factor, by its nature or a marginal difference from the reference in-use can be omitted from the estimation using this method.

The 'Factor Method' can be applied to both components and assemblies. When applied to the assembly, the interface between different materials, as well as the components themselves, needs to be considered. Two or more agents can act (or counteract) to produce an effect greater or smaller then the sum of their individual effects.

2.6.2 Levels of Application

Four levels of 'Factor Method' can apply to different limitations and needed situations.

1. *Checklist Level*: It is the simplest method, but requires the highest skill and experience of users. The estimator's uses his experience combined with the overall differences between the specific object and the reference in-use condition in each factor in order to obtain a reliable result.

2. *Multiplication Level*: The method estimates the life of a component by adjusting the reference service life with a modified factor that relate to the specific conditions. Each factor reflects the relative difference between the object specific and the reference in-use condition. The factor method therefore can be expressed in the following formula:

$$ESLC = RSLC \times Factor\ A \times Factor\ B \times Factor\ C \times Factor\ D \times Factor\ E \times Factor\ F \times Factor\ G \qquad \text{(Equation 2.1)}$$

Where ESLC is Estimated Service Life of a component
RSLC is Reference Service Life of a component

A numerical factor can have a value between 0 to infinity; a value less than 1 has a reducing effect, while more than 1 has an increasing effect. The ISO 15686-8.2 suggests that all factors should have value in the interval of 0.8-1.2, or more preferably between 0.9-1.1. The narrow range of values is preferred due to the inherent uncertainty of the method. By means of multiplication, the relative level of overall uncertainty increase as the deviation of the factor value from unity increases.

3. *Function Level*: The function level is only employed in particular cases when a service life model is available. The estimation is carried out by multiplying the reference service life with an appropriate mathematical function of the variables A-G.

4. *Combined Level*: Estimated service life can be calculated by combining the multiplication and function for groups of different factor classes.

5. *Additional Method (Probability Distribution)*: Given the time-dependency and uncertainty of building component performances, it is possible to adopt stochastic process theory for the service-life prediction (Lounis, Vanier et al. 1998a). In this method, degradation is regarded as stochastic process for each component and time period to derive the probability of deterioration. By transforming time-dependent probability into a time-independent model, users can overcome the shortfall of factor methods and avoid the sophisticated full-time dependent probability approach (Wolf 2003)

2.6.3 'Factor Method' Problems and Criticisms

At the present time, data are rarely available or comprehensive enough to reliably indicate the degradation of even similar buildings or components (ISO 2006). Users, therefore, arbitrarily choose the adjusting factors and reference service life (RSL) based on the availability of deterministic data/information. This process, however, tends to disregard all uncertainty and variability of service life, or intentionally ignore some important factors due to the financial constraints (Wolf 2003). Lounis, Lacasse et al. claim that the service prediction factors have stochastic nature; therefore, the outcome should not be a single value but ranges of values that account for the uncertainty (Lounis, Lacasse et al. 1998; Wolf 2003). ISO 15686, nevertheless, suggests a built-in uncertainty by stating that an 80% confidence limit should be used for the estimation purpose for maintainable components, while non-maintainable inaccessible components may need a higher level.

All buildings and their environments are generally unique; therefore, estimating the service life of building systems and its components can be very complex with various factors and conditions (intensity, frequency, etc.). For example, the wide ranges of climate and construction techniques are different, which may require many separate factors for service life planning to be developed for specific circumstances. A precise and reliable forecast of service life is extremely difficult.

Some researchers, however, have criticized that although the 'Factor Method' is simple, its simplicity can be considered both a benefit and a limitation. The simplicity can deceive the user to underestimate the complexity of the actual degradation process (Lounis, Vanier et al. 1998a). There is considerable work to be done before the 'Factor Method' can be proved to be reliable and consistent, despite confirmation from the Architectural Institute of Japan (AIJ) that the method is achievable using an empirical approach.

Another concern is with the degradation that often commences at interfaces between two or more materials; however, data on performance on such areas are often omitted from testing. It is, therefore, important to forecast not only the material or component performance, but also the effect of interfaces on the performance of the larger system. Masstison, however, argues that the interaction implication in the factor method has already been accounted for in the reference service-life value (Marteinsson 2003).

2.7 Conclusions: Point of Departure

Building roofs regularly suffer from premature failures and leaks that lead to business interruptions and lost of opportunity costs. The nature of the roof and its location, and the misjudgment of warranty are some of the reasons for these problems. The biggest problem is, however, the lack of roof proactive strategic maintenance.

Various methods and tools have been proposed to assist in roof maintenance tasks. To accomplish this goal, however, some techniques require a large amount of time and financial commitment. Some efforts require staff to be highly skilled in mathematics to perform a fairly complicated statistical analysis and interpretation; this is a requirement that often goes beyond the capabilities of maintenance personal. In addition, many existing methods are still considered to be quasi-reactive approaches, in which maintenance decisions are made based on visible irregularities on roofs.

Other research efforts center on working to improve or discover new roof material formulas in laboratory tests, which has resulted in high-quality roof material with superb testing records. However, roofs in the real world and the ones in the tested facility sometimes react differently to the environment due to unknown and unforeseen factors.

A new approach, involving proactive roof maintenance, is therefore needed to be planted in practitioner's minds, in order to change the roof maintenance management attitude. The generic and easy-to-use 'Factor Method' has shown promise as a way to satisfy the need for proactive maintenance practice. There is, however, additional work that has to be done before the 'Factor Method' can be applied to the roof domain.

This investigation takes a step beyond the traditional way of managing building roofs by proposing a new proactive roof maintenance approach. It involves exploratory data analysis to identify root causes of roof premature failure and investigates the use of "Factor Method' in predicting a roof service life. This research departs from:

1. The knowledge gained from previous research efforts and the industry knowledge regarding potential causes of leaks to analyze for the real root causes of roof leaks, and;
2. The well-defined factor classes that impact the building components' performance and the proposed method 'Factor Method' to estimate the service life of roofs.

The following chapters discuss the significant variables, the investigation, model development and 'Factor Method' investigation.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Purpose

The purpose of this chapter is to describe the research methodology used in this dissertation. The chapter has four main sections. The first part focuses on the study goal and research approaches. The objective is to provide the outlines of the tasks to be performed. The second section, variable identification, describes the process and outcome from the expert interviews. The process of selecting variables to represent the identified factors and the final list of potential causes of roof leaks are also presented.

The third part deals with data acquisition and preparation. Problems experienced during data collection, sample building characteristics and data sources are explained. Each variable and its coding detail are then explained. The final section deals with preliminary data analysis. This section aims to provide general information regarding the relationship between individual variables and leak incidence.

3.2 Research Methodology

The goal of the study is to use the results of new knowledge to provide facility managers with critical information to effectively manage their roofs. The study embarks on two different approaches: 1) Impartially and systematically identify significant factors that subject the roofs of existing warehouse-type buildings to exterior water penetration, and then use statistical tools to validate the finding; and, 2) Examine well-established methods, 'Factor

Method' that claim to improve the effectiveness of maintenance planning and investigate potential usage in the roof management field.

3.2.1 Research Approach One: Historical Maintenance Data Analysis (HMDA)

In the first approach, the study focuses initially on exploring, defining, and analyzing potential causes of roof leaks using the expert interview and literature search methods. A roof is treated as a complex system composed of many intricate relationships among roof and other connected components. Roof leaks are also complex phenomena which occur due to different combinations of factors (events, components, etc.). Due to their function and position, roofs are generally subjected to a variety of intrusive agents and mechanisms. Both endogenous and exogenous parameters that potentially lead to exterior water penetration on roofs are considered from the designer, roof installer and facility maintenance knowledge domains.

Roof problems are defined as any roof conditions that subjected a roof to leaks. Using variables gathered from the previous step, model creation, analysis, and interpretation is then performed. A second independent source of data is used to validate the generalization of the final model. In this study, the terms 'factor', 'variable', 'parameter', and 'cause' of roof leaks are used interchangeably.

The study is based on two fundamental principles, which stand directly opposite each other along the research spectrum. One research principle assumes that roof leak phenomena can be explained by current science knowledge. By thoroughly analyzing leak incidences, mechanisms, and conditions using physical reasoning logics, the true causes and relations among them can be revealed. Information on the roof, such as the roof's maintenance records and other relevant data, is used to test and confirm the finding. This approach is referred as 'Physical Reasoning Approach' or PRA.

The other principle assumes roof leaks are a complex phenomenon. A roof is a multi-component system with multiple failure modes (Lounis and Vanier 2000). Leaks involve various factors that can not be easily imitated in a man-made setting, nor can traditional knowledge totally or clearly explain the incidences. This second approach is grounded in the notion that the true causes of roof leaks were unknown, and to disclose them, the fewest number of possible hypotheses were assumed. By learning from real roofs and the power of statistical tools, new knowledge regarding roof leaks can be unveiled. This approach is now known as 'Black Box Approach' or BBA.

Although both methods (PRA and BBA) start out from different sides of the spectrum, they both expectedly yield the same results regarding the causes of leaks. Figure 3.1 depicts the two approaches and their relationship.

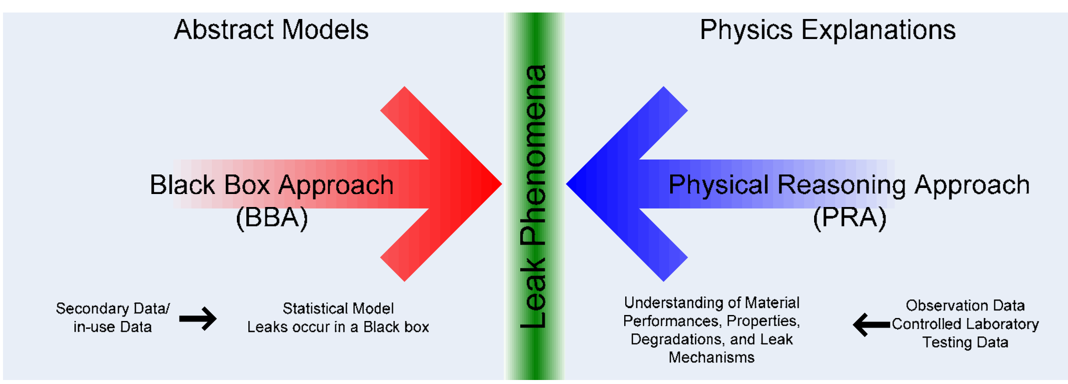

Figure 3.1 Research Approaches

3.2.1.1 Physical Reasoning Approach (PRA)

The initial decision is to proceed with the PRA, using known science to explain and identify cause of roof leaks. This approach assumes physical reasoning can explain how and in what conditions water could be transported into buildings. All possible external water intrusion mechanisms on roofs topology are captured on a study matrix. While the X-axis represents water intrusion mechanisms, the Y-axis represents roof topology. By comparing the types and locations of leak incidences recorded in the maintenance history to the study matrix, the true causes can be unearthed.

In order to describe and represent the exact shape and position of roofs, the boundary representation method, using object geometries, is employed (Marshall 1994). A roof is divided into different physical geometries based on numbers of planes connected at one point in roof space; for example, the roof field has only one flat plane/surface/dimension, while roof parameters have two perpendicular planes (edge-straight lines or circular arcs). The areas around equipment curbs on roofs have three different directional planes; the vertex positioning in space as given by its x, y, and z coordinates, as shown in Figure 3.2.

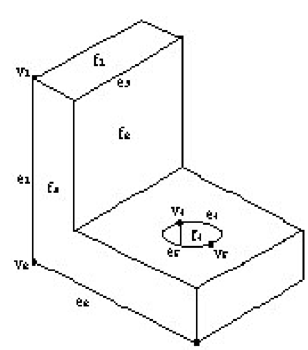

Figure 3.2 Boundary Representation (Source: Vision systems (Marshall 1994))

The PRA however, is abandoned based on three main concerns:

1. After preliminary interviews, roof experts point out that human involvement with roof projects, either as designers or maintenance staff, contributes greatly to roof leak problems, and, for the most part, are the major cause of roof leaks. Materials, on the other hand, caused fewer problems, if the roofs are installed properly. New technologies and improvements to roof chemical formulas, quality controls and production processes are some reasons for this conclusion. This information is consistent with Kubal's 99 percent principle, in which he claims that approximately 99 percent of waterproofing leaks are attributed to causes other than material or system failure (Kubal 2000).

2. The initial investigation of roof maintenance history records show there is not enough detailed information to explain roof problems or to identify leak locations.

3. Localizing a leak leads to erroneous conclusions since water can travel far within constructed roofs.

3.2.1.2 Black Box Approach (BBA)

In this approach, roof leaks are treated as incidences that occur in a black box; meaning that there is more than one incident or variable involved in causing leaks. Infinite combinations of incidents, from design and installation to maintenance, can cause roofs leaks. For example, if there are no design/detail errors and no false installation, the roof can still leak if the maintenance is not carried out properly. Also, if there is no false design, but there are problems with improper installation, good maintenance can catch the problem before it gets out-of-hand. By adopting this paradigm, the next question to answer is whether or not leak incidences are stochastic or deterministic. In other words, the study is interested in testing whether or not roof leak incidences are random or predictable. If it is predictable, can it be expressed in mathematical terms?

3.2.2 Research Approach Two: Roof Service Life Prediction (RSLP)

The second goal of this research is to investigate the claim that the availability of service-life prediction tools can increase a maintenance program's reliability and effectiveness (Shohet and Paciuk 2006). In this context, the research seeks to investigate the claim that service life prediction can improve the roof maintenance efficiency. The service life, in this context, is defined as a 'period of time after installation during which a building or its parts meets or exceeds the performance requirements' (ISO 2000).

A number of different approaches to estimate the service life of building materials and components are available, and are explained in the literature review chapter. One of many new methods, ISO 16868 'Factor Method', proposed by the International Standard Organization (ISO), is adopted as a means to estimate the service life of building components for this investigation. Although it is heavily criticized as subjective, the 'Factor Method' is selected because it was simple and easy-to-use. Because it is based on the availability of data, it is suitable for the industry's current situation in which important information is still lacking.

For building roof maintenance, a significant requirement is to prevent water penetrations from exterior leaks. In this research, the moment right before a roof leak occurs is assumed to be the most-effective time to perform a maintenance task. Roof leaks are inarguably a sign of problems that lead to a roof premature failure that ends a roof service life. Therefore, for a longer roof life, leaks are expected to occur much later on its life than a roof with a shorter life span. Based on these claims, the research hypothesizes that the timing of roof leaks and the roof assembly's service life are in some way related. Because the study merely aims to prove the usefulness of the 'Factor Method' in the roof maintenance plan, only the first-time leak is captured and used, in order to simplify the analysis process.

This study seeks to prove, based on the 'Factor Method', whether or not it is true that it takes more time for a roof with a longer estimated service life to leak; or in other words, if roofs that leak earlier in their lives have a shorter estimated service life than roofs that do not leak at the same age. The hypothesis for this stage then reads as: "The first leak time of the roof has a linear relation with the estimated roof service life using 'Factor Method' technique".

3.3 Research Methodology Outlines

3.3.1 Historical Maintenance Data Analysis (HMDA) Outline

The following section outlines and briefly explains the main phases of HMDA. Step One and Step Two are explained in more detail later in this chapter. Steps Three and Four are presented in Chapter 4; while Step Five is presented in Chapter 6. Five major steps undertaken as part of HMDA are:

Step One: Explore and identify potential roof leak parameters.

Step Two: Collect and prepare relevant data for analysis.

Step Three: Select modeling techniques, create, and calibrate models.

Step Four: Validate models (internal and external).

Step Five: Analyze and interpret the results.

Note: The following terms are used interchangeably in this dissertation.

Dependent variables = outcome, response, "y"

Independent variables = covariates, prediction, explanation variables

Step One: Explore and Identify Potential Roof Leak Parameters

The first step is to explore and understand roofs and how human involvement with roofs can lead to potential problems. In this study, single-ply roof membranes commonly used in commercial buildings are chosen as a study subject.

To identify potential causes of roof leaks, one-on-one expert interviews are conducted. A literature review is performed simultaneously to gather initial information and to supplement knowledge gathered from the expert interviews. A more-thorough description of this task is detailed in the "Variable Identification" section.

Step Two: Collect and Prepare Relevant Data for Analysis

The variables from the interviews are classified into groups based on their similarity. Later in this study, these groups prove to be similar to factor classes proposed in the ISO 15686- 'Factor Method'. The final list of variables is then used as a guideline for data collection purposes. Target data sources are from the roof experts' organizations. After data is obtained, the next step is to evaluate and prepare the data for the analysis. Missing data and other discrepancies are identified and dealt with. More detail regarding this step is presented in "The Data Acquisition and Preparation" section.

Step Three: Select Modeling Techniques, Create and Calibrate Models

After all the data are collected and finalized, the research advances to the next step: selection of the mathematical modeling technique. By setting up requirement criteria, a suitable modeling technique that can answer the research question can be identified (Pallant 2005). The following are the three main requirements for choosing modeling techniques:

1. Natures of variables: From the data collection step, it is clear that data to be received are in various forms, including numbers (discrete and continuous) and texts. The tools employed, therefore, have to be able to handle such requirements.

2. Questions to be addressed: The ultimate goal of the research is to identify relationships among variables and leaks. The tools need to be able to execute the required tasks.

3. Outcome variables: The last factor that highly affects the choice of modeling techniques is the characteristics of the variable to be predicted. In this study, the outcome of the study is 'roof leaks or no leaks'. When the dependent variable has only two values, it poses difficulties and violates some assumptions of many statistical techniques; for example, the multiple regression analysis and discriminate analysis, which seem suitable for the tasks (Norusis 2005). The binary nature of the study dependent variable undeniably influences the choice of modeling techniques.

Binomial (or binary) logistic regression analysis has the ability to satisfy all three of the identified requirements. It is suitable for research problems with binary dependent and categorical or continuous independent variables. Logistic regression analysis works by modeling the probability that an event (outcome) will or will not occur. Because it is a type of regression, it has the power to model the relationship between one or more predictors and an outcome with fewer assumptions than other techniques (Norusis 2005). Regression is the most widely used non-experimental data analysis technique (Menard 1995).

Because of a foreseeable problem with an unbalanced ratio of observed cases and predictors, a starting model with different variable selection approaches is proposed. This process not only filters out unimportant variables, but also tests the research hypotheses. The limitation of observed cases, however, only allows main effects and two-way interaction to be performed.

After the starting models, which contain potential leak predictors, are finalized, the final model is performed using logistic regression analysis. Model improvements are also carried out, in order to find the best-fit solution and to explain what variables contribute to leaks. A brief explanation of logistic regression analysis and description of the detailed steps undertaken are explained in Chapter 4: Model Development.

Step Four: Validate Models

There are two levels of model validation: internal and external. The purpose of the internal model validation is to examine how well the model fits the data or misclassification on the test set (Moore 2007). The k-folder cross validation is chosen for this purpose. It is generally a better model evaluation method than residual or holdout methods (Schneider 2006). However, some researchers prefer bootstrapping techniques or leave-one-out cross-validation techniques. Bootstrapping requires a much higher and more-extensive computation, but provides stable estimates with low bias (Harrell 1997; Steyerberg, Harrell et al. 2001; Tseng, Rajan et al. 2005). Leave-one-out cross-validation often works well for estimating generalization error for continuous error function; for discontinuous error functions, such as misclassified cases in logistic regression analysis, the k-folder cross-validation is preferred (Anonymous 2004).

In k-folder cross validation, the data set is divided into *k* subsets. Each time, one of the *k* subsets is reserved as the test set; the rest are used as a training set. The average error across all *k* trials is computed and compared with the error produced from the full model. The model is generalized when the each outcome produces relatively similar results (Field 2005).

The second validation step, external validation, confirms that the derived model not only fit the training data, but also the population from which the sample data are drawn. A total of 60 random selected roofs (20% of training data in the first set) are used to test the model's prediction capability.

Step Five: Analyze and Interpret the Results

The final mathematical model is presented in this step. This model shows the relationship of each predictive variable with detailed explanations. Influence variables and their contribution effects are identified and revealed. This new finding reinforces the need for roof maintenance, and is used to develop a roof maintenance guideline for facility managers.

3.3.2 Roof Service Life Prediction (RSLP) Outline

There were six main steps in this investigation. They are:

Step One: Understand the Factor Method Technique

The research starts with learning the significance, scope, and intended information represented in each factor class (A to G). This step is accomplished through an exhaustive and comprehensive literature review. The ISO 15686 Part 1-General Principles, Part 2-Service Life Prediction Procedures, and Part 8-Reference Service Life and Service-life Estimation are used as reference sources.

Step Two: Identify Variables in Roof Domains

Variables in roof domains that meet criteria of each factor classes are identified. These variables are now called 'Roof Factor Class or RFC'. Then, each identified RFC is examined and matched to the variables collected during the expert interviews in HMDA. Some factor classes could have more than one sub-factor (sub-RFC), depending on the physical reasoning and interpretation of factor classes. This process is subjective, due to lack of clear guidelines of how or what variables should be used.

Step Three: Create Rating Levels for Each Factor Class

Each RFC and sub-RFC is then divided into subgroups. Three or five ratings are created to represent different intensity levels within each factor class (Rudbeck 1999). For example, the average rainfall per year can be 1-5 inches (level 1), 6-10 inches (level 2), and more than 11 inches (level 3) for the three levels of group factors. Due to the lack of the possible value extent and dose-response knowledge of each identified RFC, the collected data ranges are evenly divided to create different rating levels (three or five levels). An assumption of normality, uniformity, and linearity of dose-response is also presumed. Each observed case is then classified according to their observed values.

Step Four: Assign Case-specific Values to Each Factor Class' Subgroups

Each rating level is then given a value representing specific conditions compared to the reference case (RSL). Two different sets of values are assigned to the rating levels using similar principles. They are: 1) Set one, based on ISO recommendations. The values are 0.90, 0.95, 1.00, 1.05, and 1.10. 2) Set two, using grading method as explained in section 2.6.1 and Table 2.1 with minor adjustments. The values are 1, 3, 5, 7, and 9. In this method, 1.00 from the first set, and 5 from the second set are represented as neutral and equal to the reference case. The values 0.95 and 1.05 from the first set, and 3 and 7 from the second set, represent one level stronger or weaker condition than the neutral. Values 0.90 and 1.10 from the first set, and 1 and 9 from the second set, represent two times the condition of the reference case. From the previous average annual rainfall example, if level 2 is set to be the reference point and less amount of rain is assumed to be better for roofs, then level 1 (rain 1-5 inches) takes a value of 1.05 or 7 (one level better than the reference case), and level 3 (rain more than 11 inches) takes a value 0.95 or 3 (a level worse than the reference case).

Step Five: Determine the Value of Each Factor Classes

In some factor classes, there are multiple RFC. In this case, since there is no clear direction on how to handle this issue, the following trial and error methods are adopted to derive the represent value of a particular factor class (factor A-G).

1. Multiply sub-factor to make up the class factor; for example,

Class A = factor A1 x Factor A2 x Factor A3 (Ai = sub-factor, i = n)

2. Average sub-factors to make up the class factor; for example,

Class A = (factor A1+ Factor A2 + Factor A3) / 3(i) (Ai = sub-factor, i = n)

3. Add sub-factors to make up the class factor; for example,

Class A = factor A1 + Factor A2 + Factor A3 (Ai = sub-factor, i = n)

4. Select only single most important sub-factors based on literature.

Step Six: Analyze Relationship

The last step in this approach is to analyze the relationship between first-time leaks and estimated service life, using the same software package proposed in HMDA. The Pearson correlation analysis, which assumes the data are normally distributed, is selected as a means to derive the analysis results. The correlation efficiency size is interpreted using Cohen's suggestion, as presented in Table 3.1 (Cohen and Cohen 1983).

Table 3.1 Interpretation of Correlation Size

Correlation	Negative	Positive
Small	-.29 to -.10	.10 to .29
Medium	-.49 to -.30	.30 to .49
Large	-1.0 to -.50	.50 to 1.0

3.3.2.1 Additional Assumptions

Three different attempts to identify correlation between the estimated service life and the first time leak are proposed. The first attempt (TFA) includes all 310 observed roof cases, both leaks and no leaks in the data pool. The second attempt (TSA) uses solely leak cases in the observed cases. The third attempt (TTA) separates leak cases based on specific criteria.

TTA is based on one assumption that there may be some patterns in different types of leaks, such as leaks caused by human accidents or those that were environmentally induced. The collected maintenance recodes, however, do not contain or can be used to disclose such information. Based on the information available, the nature of leaks can be identified as: 1) spreading throughout the store; and, 2) spotted leaks. This is then used as criteria to differentiate the leak incidents.

Although the ISO-15686 Part 1 suggests using only degradation agents for Factor E, outdoor environment, other related variables, such as micro environment or changes of temperatures, can also potentially impact roofs. Therefore, their variables are included as additional sub-factors to test the hypothesis.

3.3.2.2 Omitted Factor Classes

Factor class B: Design Level and Factor class D: Indoor Environment are not included in the investigation, as described later in Chapter 5.

3.3.2.3 Reference Roof Materials and Conditions

The reference roof in this investigation contains the following characteristic: A reinforced single-ply membrane material using heat-weld seams roof located in a moderate year-round temperature, mild wind speed, and 30-70% open space with no maintenance.

The different combinations of the four main factors shown below create 56 different trails. The purpose of these trials-and-errors is to identify any relationships between the first-time leak and estimated service life, based on the 'Factor Method' technique. The summary of the each trial is presented in Table 3.2.

1. Coding System (ISO or Grading)
2. Derivation of Factor Class Value (Single, Multiply, Average, or Add Sub-factors)
3. Additional Sub-factor Included (Yes or No)
4. Data Used in Analyses (TFA, TSA, or TTA)

Table 3.2 Summation of Approaches to Find Relationship between ESL and First-Time Leaks

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 1	x		x					x			
Trial 2		x	x					x			
Trial 3	x			x				x			
Trial 4	x			x			x	x			
Trial 5		x		x				x			
Trial 6		x		x			x	x			
Trial 7	x				x			x			
Trial 8	x				x		x	x			
Trial 9		x			x			x			
Trial 10		x			x		x	x			
Trial 11	x					X		x			
Trial 12	x					X	x	x			
Trial 13		x				X		x			
Trial 14		x				X	x	x			
Trial 15	x		x						x		
Trial 16		x	x						x		
Trial 17	x			x					x		
Trial 18	x			x			x		x		
Trial 19		x		x					x		
Trial 20		x		x			x		x		
Trial 21	x				x				x		
Trial 22	x				x		x		x		
Trial 23		x			x				x		
Trial 24		x			x		x		x		

Table 3.2 (Continued)

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Arbitrary	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 25	x					X			x		
Trial 26	x					X	x		x		
Trial 27		x				X			x		
Trial 28		x				X	x		x		
Trial 29	x		x							X	
Trial 30	x		x								x
Trial 31		x	x							x	
Trial 32		x	x								x
Trial 33	x			x						x	
Trial 34	x			x							x
Trial 35	x			x			x			x	
Trial 36	x			x			x				x
Trial 37		x		x						x	
Trial 38		x		x							x
Trial 39		x		x			x			x	
Trial 40		x		x			x				x
Trial 41	x				x					x	
Trial 42	x				x						x
Trial 43	x				x		x			x	
Trial 44	x				x		x				x
Trial 45		x			x					x	
Trial 46		x			x						x
Trial 47		x			x		x			x	
Trial 48		x			x		x				x
Trial 49	x					X				x	
Trial 50	x					X					x
Trial 51	x					X	x			x	
Trial 52	x					X	x				x
Trial 53		x				X				x	
Trial 54		x				X					x
Trial 55		x				X	x			x	
Trial 56		x				X	x				x

3.4 Variable Identification

The following sections describe the process and outcome from the expert interviews. The results of the collected variables and process of selecting variables to represent the identified factors are discussed. The end of this section concludes with a presentation of the final list of potential causes of roof leaks. These results are used for the next research step.

3.4.1 Data Identifications: Semi-Structure Interviews

Expert interviews are selected as the major tool for exploring and collecting potential causes of roof leaks. Limited knowledge about the causes of roof leaks gives way to the use of a semi-structured interview technique (Naoum 1998). The interview questions are designed as a loose guideline to give the interviewees freedom to describe and share their work experience regarding roof problems. By employing open-ended questions, the interviewer can immediately ask questions relevant to new factors mentioned, as well as ask interviewees to clarify their responses. At the same time, what is already known from discussions with other experts can also be confirmed (Case 1990). A copy of survey questions is presented in Appendix B. One-on-one, semi-structured interviews are performed and a tape recorder is used with permission of the interviewee. The transcription process is performed after each interview and a summary of variables is recorded.

Semi-structured expert interviews prove to be effective, in terms of information-gathering. From the transcription process, approximately 106 raw variables are collected. These variables are then classified into groups based on their similarity.

3.4.1.1 Roof Expert Qualifications

In this study, roof experts are identified as a group of people who are involved in a roof business and specialize in single-ply membrane roof systems. Their engagement ranges from designing, specifying, maintaining or consulting, with a minimum of 10 years work experience. Due to these specific requirements, a pre-defined group of experts is selected based on a non-probabilistic sampling (Trochim 2005).

The process of selecting roof experts begins with an interview with a known, qualified facility manager. During the interview session, participants are asked to recommend other knowledgeable people who may be interested in participating in the study. By using the snowball technique (Trochim 2005), the researcher can contact and interview a number of qualified roof experts. The process is terminated when new knowledge is not added to the body of knowledge acquired in the previous interview.

Nine roof experts are interviewed and can be classified into four major groups, as shown below. After the seventh expert is interviewed, little new knowledge is added into the pool of collected variables. The last two interviews, therefore, serve more to confirm the results, rather than for explorative purposes. By interviewing different groups of experts, the researcher can explore and identify causes of roof leaks from different perspectives based on interviewees' backgrounds. This holistic approach provides insight into the leak problems and helps ensure all potential causes were thoroughly considered. The four groups of roof experts used in this study are:

1. Facility Maintenance Staff: There are four participants in this category.
2. Roof Installer: There is one participant in this category.

3. Roof Consultant: There are three participants in this category.

4. Roof Designer: There is one participant in this category.

3.4.2 Data Identification: Literature Search

A comprehensive search of refereed journals, the Internet, trade magazines, and other publications is performed as a secondary knowledge-gathering tactic. The purpose of this process is to: 1) define a starting point for the research; 2) confirm the factors collected from the expert interviews; and 3) use supplemental knowledge from the interviews. The focus of the literature search is not only on single-ply membrane roofs, but also on roof problems in general.

3.5 Interview Results: Potential Causes of Roof Leaks

All information gathered from interviews is classified into groups based on the similarity of the origin of causes. From the interviews, there are a total of 27 possible causes of roof leaks that can be classified into five different groups, as presented in Table 3.3. The exhaustive list of variable collected is presented in Appendix C.

Table 3.3 Summary of Potential Causes of Roof Leaks Collected From Expert Interviews

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	# Experts
Maintenance				
	Physical damages (punctures) from human, human working on roofs	Physical damages (punctures)	Human working on roofs	9
	Lack of maintenance	Deteriorated materials compromised roof's integrity (water tightness)	Lack of maintenance	7
	Roof alterations	Compromised roof's integrity (water tightness)	Human working on roofs	4
	Facility conditions induced problems	Compromised roof's integrity (water tightness)	Human decisions	4
Design				
	Error design/details	Compromised roof's integrity (water tightness)	Error design/details	8
	Complex design/details	Error prone/ compromised roof's integrity (water tightness)	Complex design/details	3
	Designer qualifications	Error prone/ compromised roof's integrity (water tightness)	Insufficient knowledge regarding roof systems	3
	Material/ system choices	Error prone/ compromised roof's integrity (water tightness)	Insufficient knowledge/ unfamiliar with the systems	8
	Penetration details/choices	Error prone/ compromised roof's integrity (water tightness)	Insufficient knowledge/ not enough attentions	4
	Material/ system compatibility choices	Error prone/ compromised roof's integrity (water tightness)	Insufficient knowledge/ not enough attentions	9
	Insufficient design criteria	Error prone/ compromised roof's integrity (water tightness)	Insufficient knowledge/ unfamiliar with the systems	3
	Connected system onto roofs (roof equipment/components)	Error prone/ compromised roof's integrity (water tightness)	Lack of knowledge/ compatibility/ planning/ continuity	7
	Too much/little owner involvements	Compromised roof's integrity (water tightness)	Owner involvements	6

Table 3.3 (continued)

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	# Experts
Installations				
	Installation errors caused from details/design	Compromised roof's integrity (water tightness)	Detail errors/complicated details	5
	Installation errors caused from installers	Compromised roof's integrity (water tightness)	Improper installation/ did not follow or pay attention to instruction	8
	Installation Errors caused from environment	Error prone/ compromised roof's integrity (water tightness)	Environment	4
	Lack of quality crews	Error prone/ compromised roof's integrity (water tightness)	Crew quality	8
	Physical damages	Damaged materials/ compromised roof's integrity (water tightness)	Human working on roofs	3
	Lacks of construction administrative	Error prone/ compromised roof's integrity (water tightness)	Lack of quality control	7
Environment				
	Age	Deteriorated materials	Age	3
	Local settings (micro-environment)	Physical damages	Local settings (micro-environment)	4
	Weather patterns	Deteriorated materials/ physical damages	Weather patterns	1
	Environment-induced damages	Physical damages	Environment	6
	Temperature/heat	Damage/deteriorate materials	Temperature/heat	7
Others				
	Material defects	Compromised roof's integrity (water tightness)	Manufacturer's problems	3
	Industry problems	Error prone/ compromised roof's integrity (water tightness)	Industry problems	4
	System weak-points	Error prone/ compromised roof's integrity (water tightness)	System weak points	9

In general, most of the nine roof experts have similar opinions regarding the causes of roof leaks. About 50% of the issues listed are mentioned by more than half of the roof experts as either contributing or not contributing to leaks. Three issues are agreed by all experts as potential causes of roof leaks. They are: 1) physical damages caused by humans working on roofs; 2) material and system compatibility; and 3) inherent weak-points in the system. Seven to eight experts mention that roof leaks are caused by: 1) lack of maintenance; 2) error details from designers; 3) bad choices of materials or systems selected; 4) other systems connected to the roof; 5) installation errors (installer faults); 6) low-quality crews; 7) lack of quality control during installation; and 8) temperature or heat. Five to six experts recite that: 1) owner involvement; 2) installation errors due to design/detail errors; and 3) environment-induced damages are the factors involved with roof leaks. The other half of the list is agreed by two to four experts. A single roof expert did mention weather patterns as a cause of roof leaks. In this case, the expert did not believe that the weather pattern increased or reduced chances of leaks.

The raw data in Appendix C also reveal that approximately 40% of issues mentioned in the interviews originated during the pre-construction (design) phase. Twenty-six percent and 15 percent involve human involvement during installation and maintenance, respectively. The remaining 19 percent are almost equally split between environmentally-induced problems and other issues.

Some variables showed inconsistent opinions among experts, as shown in Table 3.4. For example, two experts disagreed that the availability of walk pads on roofs helps prevent damage (punctures) to roof membranes caused by foot traffic. The experts stated that the walk pads are not used. An equal ratio between agree and disagree is observed with the issue of material defect. Two experts strongly believed that roof problems typically do not originate from the material itself. The rest of dissenting opinions involve selections or compatibility of components selected.

Table 3.4 Inconsistency of Roof Expert Opinions

Descriptions (problems caused from …)	Samples/reasons/activities	Total	Disagree
Physical damages (punctures) from human	Lack of walk pads	3	2
Material/ system choices	Material: Membrane thickness	3	1
	Choices-fastener interval	3	1
Material/ system compatibility choices	Choices-materials VS applications	5	1
	Choices-roof deck-suitable for different membranes, insulation	2	1
Weather patterns	Weather/temperature patterns	1	1
Material defects	Material defects	3	2

3.5.1 Claims: Major Roof Leak Periods

Approximately one-third of the roof experts strongly believe that the majority of leaks occur in two milestones in roof lives. They are: 1) during or immediately after the installation was completed; and 2) toward or near the end of the service life of roof's components. The experts reason the cause of the first type of leaks is from errors during installation. If the roofs are not installed properly, they will exhibit the problem immediately. The latter cause is from general material wear and tear, and typically took a longer time to appear as a problem. This notion coincides with experts who believe that many problems originate from installation and maintenance. The reasoning is that, if there were errors in design, good roof installers are able to catch the problems and fix them during installation.

3.5.2 Interviewed Variable Analysis: The Final List of Roof Leak Causes

From the interviews, 106 raw causes under 27 different causes are used as a guideline for data collection. From the preliminary investigation, it is clear that not all identified variables, such as crew attitudes, can be quantified and obtained for analysis. In real life, the amount and type of facility information collected, maintained, and made available depends on individual organizations; this directly impacts the data acquisition process. In this study, some data for some variables are the same in all cases, such as the internal uses or store conditions. In some cases, some data can be used in more than one variable. Some identified variables are impossible to collect and others do not apply to the research sample.

In this sample, data is obtained from one retail chain that owns multiple warehouse-type retail stores across the United States. These stores generally have similar structures, components, and configurations. In terms of roof installation, the company purchased and had an agreement to use products and installation crews with a sole manufacturer.

Tables 3.5 and 3.6, present the process of deriving the final variables used in the mathematic model development. Table 3.5 displays eight causes (in italics) that were assumed to: 1) have same values in all cases; 2) be unavailable; or 3) not be applicable to the study. Three roof causes in this table have only partial information available. Table 3.6 presents the list of roof leaks causes after eliminating eight variables identified in Table 3.5. The duplicated quantified variables in the 'final variables' column in Table 3.6 are eliminated to derive the final list of variables.

Table 3.5 Summary of Quantified Variables in Each Potential Cause of Leaks

Phases	Descriptions (problems caused from …)	Expert	Quantified variables	Availability	Source	Note
Maintenance						
	Physical damages (punctures) from human, human working on roofs	9	Roof damages reported/ frequency of staff on roofs	Yes	Maintenance records	
	Lack of maintenance	7	Frequency of roof maintenance-cleaning/inspection	Yes	Maintenance records	
	Roof alterations	*4*	*Frequency of roof alteration*	*No*		*Data were not captured in the database*
	Facility conditions induced problems	*4*	*Pressure levels, internal activities*	*Yes*	*Facility Information*	*Same in all roofs*
Design						
	Error design/details	8	Frequency of roof problems reported	Yes	Maintenance records	
	Complex design/details	3	Frequency of roof problems reported	Yes	Maintenance records	
	Designer qualifications	*3*	*Designer's names/companies, designer experience*	*No*		*Assume to be the same in all roofs (use the same pool-prototype of drawing and specifications)*
	Material/ system choices	8	Types of roof materials used - membrane thickness, width, model, formula	Partial	Facility information	The majority of materials used are the same based on materials (brought directly from a single manufacturers)
	Penetration details/choices	*4*	*Penetration choices - prefabricated booth, pitch pan, collecting boxes*	*No*		*Assume to be the same in all roofs (details and specifications came from the same pool)*
	Material/ system compatibility choices	9	Types of roof systems/details used - attachment, drainage	Partial	Facility information	The majority of systems and details used are based on prototypes (based on the size of stores)
	Insufficient design criteria	*3*	*Criteria used for design*	*No*		*Assumed to be the same*
	Connected system onto roofs (roof equipment/components)	7	Numbers of penetrations on roofs, patterns of penetrations	Partial	Facility information	
	Too much/little owner involvement	*6*	*Owner requirement*	*No*		*Assumed to be the same*

Table 3.5 (continued)

Phases	Descriptions (problems caused from …)	Expert	Quantified variables	Availability	Source	Note
Installation						
	Installation errors caused from details/design	5	Frequency of roof problems reported	Yes	Maintenance records	Within the first year
	Installation errors caused from installers	8	Frequency of roof problems reported	Yes	Facility information	Within the first year
	Installation errors caused from environment	4	Installation seasons	Yes	Facility information	Extract from store opening date
	Lack of quality crews	8	Workmanship-crews/ crew quality/ Installer's names/experience	Yes	Facility information	Few crews used
	Physical damages	3	Roof damage reported	Yes	Maintenance records	
	Lack of construction administrative	*7*	*Availability of consultant, roof administrators*	*No*		*Assume to be the same*
Environment						
	Age	3	Roof ages	Yes	Facility information	
	Local settings (micro-environment)	4	Local settings, geographical locations	Yes	Facility information	
	Weather patterns	1	Weather patterns/ geographical locations	Yes	NCDC, Facility information	
	Environment-induced damages	6	Wind, precipitations, relative humidity	Yes	NCDC	
	Temperature/heat	7	Temperatures, solar radiations	Yes	NCDC	
Others						
	Material defects	3	Frequency of roof problems reported	Yes	Maintenance records	
	Industry problems	*4*	*Out of study scopes*	*NA*	*NA*	*NA*
	System weak-points	9	Frequency of foot traffic, number of penetrations on roofs	Yes	Facility Information, maintenance records	

Table 3.6 Summary of Roof Leak Causes After Eliminating Eight Duplicated and Redundant Variables and the Final Variables

Phases	Descriptions (problems caused from …)	Experts	Quantified variables	Final variables
Maintenance				
	Physical damages (punctures) from human, human working on roofs	9	Roof damages reported/ frequency of staff on roofs	1. Roof problems reported 2. Frequency of staff on roofs
	Lack of maintenance	7	Frequency of roof maintenance-cleaning/inspection	1. Frequency of roof maintenance
Design				
	Error design/details	8	Frequency of roof problems reported	1. Roof problems reported
	Complex design/details	3	Frequency of roof problems reported	1. Roof problems reported
	Material/ system choices	8	Types of roof materials used - membrane thickness, width, model, formula	1. Membrane types
	Penetration details/choices	7	Number of penetrations on roofs, patterns of penetrations	1. Numbers of penetrations
	Material/ system compatibility choices	9	Types of roof systems/details used - attachment, drainage	1. Roof prototypes
Installations				
	Installation errors caused from details/design	5	Frequency of roof problems reported	1. Roof problems reported (first year)
	Installation errors caused from environment	4	Installation seasons	1. Installation seasons
	Lack of quality crews	8	Workmanship-crews/ crew quality/ Installer's names/experience	1. Crew names
Environment				
	Age	3	Roof ages	1. Roof age
	Local settings (micro-environment)	4	Local settings, geographical locations	1. Local settings
	Weather patterns	1	Weather patterns/ geographical locations	1. Geographical locations (weather patterns)
	Environment-induced damages	6	Wind, precipitation, relative humidity	1. Wind 2. Precipitation 3. Snow 4. Relative humidity
	Temperature/heat	7	Temperatures, solar radiations	1. Temperature 2. Temperature different within a day 3. Solar radiation
Others				
	Material defects	3	Frequency of roof problems reported	1. Roof problems reported
	System weak-points	9	Frequency of foot traffic, numbers of penetrations on roofs	1. Frequency of foot traffic 2. Number of penetration

The following variables are results from table 3.6 that are identified as potential sources of roof leaks with availability of data and included in the analysis.

1. Crew names
2. Frequency of foot traffic (staff on roofs)
3. Numbers of equipment on roofs
4. Geographical locations (weather patterns)
5. Installation seasons
6. Local settings
7. Membrane types
8. Precipitation
9. Relative humidity
10. Roof age
11. Roof problems reported/Roof repair
12. Roof problems reported (first year-workmanship issue)
13. Roof prototype
14. Snow
15. Solar radiation
16. Temperature
17. Temperature differences (min-max and from normal 30 years)
18. Wind (maximum wind and average wind speed)
19. Frequency of roof maintenance/Inspection/Cleaning

3.6 Data Acquisition and Preparation

The following sections describe the process of data acquisition and preparation. Problems experienced during data collection, sample building characteristics and data sources are presented. Each variable and its coding detail are also explained in the last part of the section.

3.6.1 Data and Problems

The final list of variables is used as a guideline for data collection purposes. Roof experts interviewed for this study are the target sources for data. During the interviews, questions are asked to assess the availability of roof information and a willingness to participate in the study. When the mentioned conditions existed, an oral agreement for using the information is pursued.

Data from a number of sources prove to be problematic and difficult to manage. At the start of the process, data from different roof experts are collected in bits and pieces. Typically, the majority of study participants do not have maintenance plans in place, have no need for data, or simply do not collect data. Roofs are only repaired when they leak and, generally, only roof vendors keep all the necessary information for work-related purposes. Only generic data, such as locations of the facility, and the most critical information, costs associated with roof maintenance, are available at the building maintenance department. This results in severely incomplete, missing or unavailable data. In some cases, the needed information can be obtained, but may have required extensive time and effort to extract from old drawings or piles of old specifications; it was possible that even this effort would not have resulted in acquiring the needed data. These problems in data collecting are typical practices for the roof maintenance industry.

The ideal source of information is an organization which owns multiple facilities with similar types and uses in their portfolio. In this study, one retail chain company agrees to provide information for the research.

3.6.2 Sources of Data

The roof data is obtained from a so-called 'big box' retail store chain. These stores have unique characteristics, yet simple configurations (described in the next section). Due to the availability and limited access to the data, only maintenance records and roof projects built from 2002 to May 2005 are collected. The stores located in 47 states in the U.S. were included in the analysis. Data from Alaska, California, and Hawaii is not used. A total of 310 stores are studied. Even though the data provider outsourced their maintenance work to local vendors where the store was located, the central maintenance department kept track of all maintenance activities in the organization's central database. The sole roof installer is also contacted for additional roof information.

The variables in the final list could be classified into the following categories:

1. Buildings/roofs physical information (materials, structures, areas, column spans, location, etc.)
2. Roof maintenance information (roof problems and conditions)
3. Other maintenance on roofs (equipment maintenance activities on roofs)
4. Environmental information (temperature, precipitation)

The majority of maintenance-related data are extracted directly from the facility maintenance database. The store/roof general information came from both the facility department and the roof installer. The last category, the environmental data, is obtained from a federal government agency.

3.6.3 The Big Box Retail Structure Characteristics

The unique character of the warehouse-type structure is its simplicity, similarity, and easy-to-build, one-story structure. They are mostly long span steel columns, with roof trust joints and steel decks. These structures typical cover vast areas between 95,000 and 115,000 square feet with open ceilings and house a variety of merchandise. Most building systems are not covered, except in the office area. The heating, ventilation and air conditioning (HVAC) units are placed on top of the structure with parapet walls enclosed. This setting proves to be economical, even though common knowledge has shown a number of problems associated with this practice. In order to receive more natural light indoors, some older stores place sky lights across the roof. The stores generally have no-to-small positive pressure. With a low cost and clean appearance, the typical roof system is single ply, specifically TPO with held-weld seam, or EPDM with mechanical attachment. In the study samples, the staff mention that almost all of the stores built from the year 2000 to the present are alike in both physical appearance and in the systems used.

3.7 Data Cleaning and Manipulation

After data is obtained, the next step is to evaluate and prepare data for analysis. Missing data and other discrepancies are identified and dealt with. The following section explains how data in each variable is collected and coded for analysis purposes. Table 3.7 presents the final variables and the sources where data was expected to be obtained.

Table 3.7 Final Variables and Sources

Variables	Sources
Crew names	Facility records
Geographical locations (weather patterns)	Facility records
Installation seasons	Facility records
Local settings	Facility records
Membrane types	Facility records
Numbers of penetrations	Facility records
Roof age	Facility records
Roof prototypes	Facility records
Frequency of foot traffic (staff on roofs)	Maintenance records
Frequency of roof maintenance	Maintenance records
Roof problems reported	Maintenance records
Roof problems reported (first year)	Maintenance records
Precipitation	NCDC
Relative humidity	NCDC
Snow	NCDC
Solar radiation	NCDC
Temperature	NCDC
Temperature different within a day	NCDC
Wind	NCDC

3.7.1 Data Collected from Facility Records

The majority of the store general information is obtained directly from the facility records kept in the facility maintenance department. Additional information is also gathered from the roof installer. The following explains how each individual variable is captured and coded.

1. Crew Names

This variable is one of the two that investigated the impact of workmanship on roofs. According to the construction team coordinator, the company used the same roof installer since the year 2002. However, after examining collected data, approximately 14% of stores' roofs are installed by other crews. Therefore, for this variable, the study investigates the workmanship between two different roof installers, the current sole installer and other installers. The following is coded in the SPSS system, and the sole installer is a reference category in this analysis.

Table 3.8 Installation Crew

Crew	Coding	Note
Other	0	
Sole Installer	1	Reference

2. Geographical Location (Weather Patterns)

This variable is selected to investigate the influence of macro weather patterns on roof problems, based on the store's geographic location. The study climate zone map is obtained from the Department of Energy website, as shown in Figure 3.3. Five climate zones are divided based on the 30-year average heating degree day (HDD) and cooling degree day (CDD) for the period 1971 through 2000. The observed store location is then classified accordingly. Zone 5 is used as a reference category in the analysis. It typically stretches out in the south from the southern part of South Carolina to the majority part of Texas and part of California and Arizona.

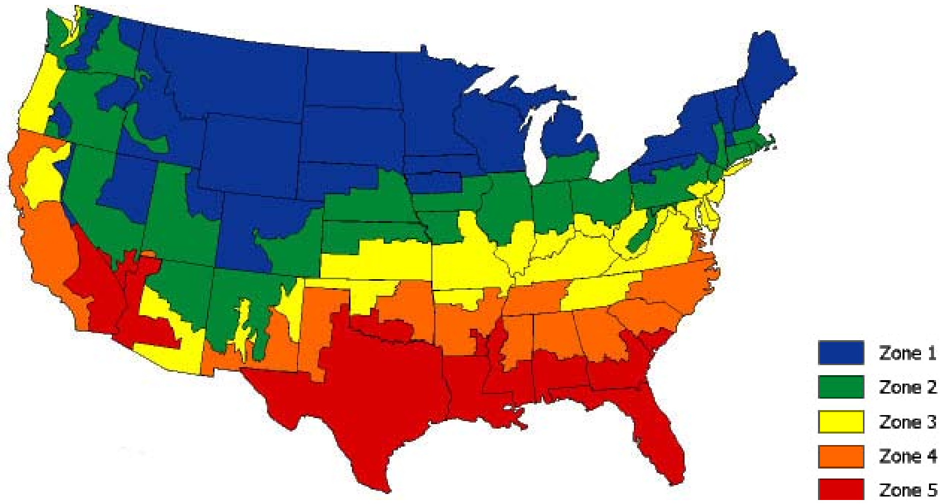

Figure 3.3 U.S. Climate Zone (Source: Department of Energy Website)

Table 3.9 Climate Zone Description

Zone	Condition	Coding	Note
Zone1	less than 2,000 CDD and greater then 7,000 HDD	1	
Zone 2	less than 2,000 CDD and 5,500 – 7,000 HDD	2	
Zone 3	less than 2,000 CDD and 4,000 – 5,499 HDD	3	
Zone 4	less than 2,000 CDD and less than 4,000 HDD	4	
Zone 5	is 2,000 CDD or more and less than 4,000 HDD	5	Reference

3. Roof Installation Seasons

This variable is intended to investigate the relationship between the time or season of roof installation and roof leaks. The exact date of roof installation is not available. However, the installation month can be accurately estimated from the store's opening date and typical construction scheduling. The construction coordinator also confirmed that during the study period, the majority of stores are built on time due to the contract and business obligations. The installation seasons are considered from the scheduled month of roof installation. The duration of each season used in this study is presented in Table 3.10. The winter season is used as a reference time.

Table 3.10 Installation Seasons Category

Seasons	Duration	Coding	Note
Fall	September to November	1	
Summer	June to August	2	
Spring	March to May	3	
Winter	December to February	4	Reference

4. Physical-Local, Micro Environment

The local setting variable investigates the relationship between the micro-environment and roof leaks. Each store is examined in terms of how it related to its specific physical environment, such as other buildings, infrastructures, and trees. The local settings are determined by comparing the percentage of open space and obstructions within a 0.5-mile radius from the store. The satellite pictures from Google Earth are acquired for this purpose. The following categories are adapted from the ground roughness (exposure) categories in Patterson and Mehta's book (Patterson and Mehta 2001) to present different micro-environment settings.

Table 3.11 Physical- Local, Micro Environment

Description	Open Space	Obstacles	Coding	Note
Urban, suburban, (near open field, grassland)	>70%	<30%	1	
Urban, suburban, wooded areas	>30% but <=70%	>=30% but <70%	2	
Urban, suburban, wooded areas	>10% but <= 30%	>=70 % but <90%	3	
Urban, suburban, wooded areas (high wooded, obstacles)	<=10%	>=90%	4	
Within city with high-rise environment	> 50%	< 50%	5	
Within city with high-rise environment	< 50%	> 50%	6	Reference

5. Material Types

The material type variable investigates different types of single-ply membranes and their relationship to roof leaks. In this study, two types of single-ply membranes are used, thermoplastic (TPO) and thermoset (EPDM). Table 3.12 presents the coding used in the analysis.

Table 3.12 Material Type Categories

Membrane type	Coding	Note
Thermoset materials: EPDM	1	
Thermoplastic materials: TPO, PVC	2	Reference

6. Numbers of Penetration on Roofs

The amount of roof penetrations is collected from the roof installer and facility staff. The penetrations on roofs generally included skylights, roof top units (RTU), vent through roof (VTR), and Roof Hatch. In this study, only information of RTU penetrations is available; therefore, it is used to represent the penetration on roofs.

7. Roof Age

Due to the fact that the exact installation date is not available, this study uses the store opening date as a reference point for measuring the roof's age. The roof age is derived from subtracting the opening date and the end of the study period (May 2005). The age in this study is represented in numbers of months.

8. Roof Prototypes

The building/roof drawings and specifications are generally from the same pool with variations in store sizes. Some slight deviations, however, are detected within the same prototypes that were built in different periods. These changes are typically reflected in the construction specifications; however, many of them are not relevant to roof configurations.

Approximately 20 percent of the study stores do not have prototype information available. Therefore, the facility size is instead used to represent the prototype. Since the majority of stores use the same roof products, roofs that have the similar area are assumed to be relatively similar in terms of components, construction means and methods, and roof details.

3.7.2 Data Collected from Maintenance Records

As described in the "Source of Data" section, data collected from maintenance records are directly extracted from the organization's central database. The following explains how individual variables are captured and coded.

1. Roof Maintenance and Problems Reported

One of the accounts in the database, roof repair, is extensively investigated. The account captures all activities on roofs, problems identified, roof repairs, and roof inspections. The real cause of leaks, however, is not easily identifiable, due to the insufficient data entry details. Therefore, roof records related to roof repair activities are classified into two groups: repairs related to leaks and all others.

In this study, requested work orders represent the number of activities on roofs. Depending on the content of the request, the frequency of each group is recorded. Some work orders contain more than one roof issue; in this case, the frequency of each task or issue is recorded separately. Multiple work orders generated within the same date for the same causes are a rare occurrence and are classified as one work order. The total roof repair frequencies are later averaged per year to derive the value for analysis.

2. Frequency of Foot Traffic

The frequency of foot traffic is captured from the number of requests for the roof installer or other maintenance staff to be on roofs. In this study, other than the roofer on roofs, regular preventive maintenance and repair of roof top units (RTU) are represented as the frequency of foot traffic on roofs.

3. Workmanship (Roof Problems Reported Within the First Year)

The number of callbacks within the first year is used as another measure of the workmanship quality. The other variable is presented in "Crew Names". The decision to include installation problems for this purpose comes from the expert interviews, as explained in Section 3.5.1.

The additional information collected from the database is: 1) both stores that have or do not have roof leaks during the period of study; and, 2) the time when the first leak incidence occurs. Stores with or without roof leaks are considered for the entire study period. If a store reports at least one roof leak, it is classified as a 'roof leak store'. Only stores with a clean history of leaks are classified as ‘no roof leaks’, regardless of their current age. The first-time leaks detected are captured for the first-time leak variable.

3.7.3 Data Collected from Government Resources (NCDC)

The majority of environmental information falls into this group. The current and historical records of the temperature, precipitation, relative humidity, wind, and snowfall are gathered from the local climate data produced by the National Climatic Data Center (NCDC), which falls under the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce. The NCDC provides official climate and weather-related data to a number of industries and businesses, including the agriculture industry, the real estate sector, law firms, and research institutions.

The annual data summary records weather-related statistics from all weather stations located at airports across the U.S. In a case where there is no weather station located in the same city as the study store, the data of the closest (distance) station is used instead. The following section explains how each item in the report is captured.

1. Snowfall and Precipitation

The normal snowfall, including ice pellets and sleet, and precipitation records from the past 30 years are extracted from the local climate data report. Both are reported in average total inches.

During the data collection process for snowfalls, some records contained information of a very small amount of snowfall; for example, ‘T’ refers to trace amount greater than zero, but less than the lowest reportable value and 0.* or *, the value between 0.00 and 0.05.

These two elements are transformed to numeric number, 0.01 and 0.02, respectively, in order to make it possible to perform the analysis.

2. Relative Humidity

The average relative humidity per month for the last 40 years is collected by NCDC. The average relative humidity, both in the morning and afternoon, for the entire year are calculated and used to represent the average relative humidity at each weather station.

3. Solar Radiation

The solar radiation represents the amount of solar radiation, both direct and diffuse, received at any location (Darling 2005). This data is obtained from the Renewable Resource Data Center (RReDC), the National Renewable Energy Laboratory. The data contains the average and standard deviation of the daily total solar energy for each station for the years 1961 to 1990. This information is used to establish the normal solar radiation at each weather station location.

4. Temperature (Temperature (30 year Average) and Deviated Temperature)

The 30-year (1971 to 2000) normal daily maximum (NDX) and minimum (NDN) temperatures are averaged and used to represent the normal temperature at each location. Two types of temperature deviations are captured in this study: 1) the average different temperatures range (max-min); and 2) the average different temperatures between the study period and the average 30-year period.

The average different temperature range (ADTR) represents the severity of temperature fluctuation in each location, and is calculated by subtracting NDN from NDX. The subtraction of ADTR during the study period from the 30-year daily normal temperature represents the fluctuation of temperature in the latter category. The difference of the temperatures is then averaged to present the fluctuation of temperatures from the norm. The fluctuations are represented in the following equations.

Average different temperature range (ADTR)

$$ADTR = NDX - NDN \qquad \text{(Equation 3.1)}$$

Average different temperature range –study period (ADTR-S)

$$ADTR\text{-}S = SNDX - SNDN \qquad \text{(Equation 3.2)}$$

Average different temperature from norm (ADTN)

$$ADTN = \frac{((ADTR) - (ADTR - S))}{2} \qquad \text{(Equation 3.3)}$$

SNDX = study period normal daily maximum temperature
SNDN = study period normal daily minimum temperature

5. Winds

Although the record-keeping period of wind speeds is inconsistent, ranging from 10 to 60 years, the majority of minimum recorded years is 30 years. Average wind speeds and two-minute maximum winds, regardless of direction, are recorded for the analysis.

3.8 Preliminary Data Analyses: Individual Variable and Leak Data Interpretation

For the preliminary analysis only, the following data are categorized as discrete variables: age; prototypes; and data collected from maintenance records. These categories are arbitrary for explanatory purpose only. The variables are treated as continuous during the logistic regression analysis.

The following abbreviations are used in the data tables throughout this chapter:

1. C% 'Column Percentage' is a cell percentage compared with other cells within the same column.
2. R% 'Row Percentage' is a cell percentage compared with other cells within the same row.

3.8.1 Roof Information Data

1. Roof Leaks

Out of 310 observed stores, 205 are classified as 'leak' stores during the time frame (40 months) of the study; 105 stores do not report any leak problems. Without considering frequency and time of leaks, the average age of 'leak' stores is twice the age of stores that donot leak, as presented in Table 3.13 and Figure 3.4 and 3.5.

Table 3.13 Study Roof Age and Leak Information (months)

	Leaks	No Leaks
Frequency	205	105
Percent	66%	34%
Mean	22.65	10.30
Minimum	4	0
Maximum	40	40

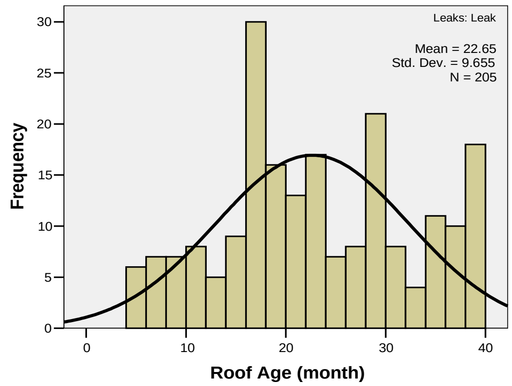

Figure 3.4 A Distribution of Store Ages with Leak

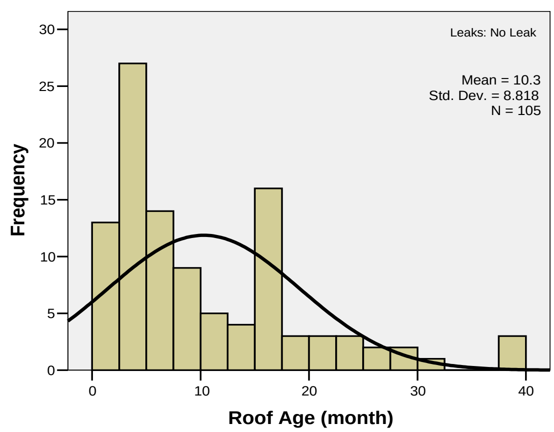

Figure 3.5 A Distribution of Store Ages with No Leaks

2. First-Time Leaks

Approximately half of the stores with leaks report the first leak within the first two months following the store's grand opening day (represented by a pointed arrow in Figure 3.6). The highest frequency of first-time leaks also occurs when the roofs are two-months-old. The number of first-time leak stores reaches 80% (146 roofs) within the following eight months (the 10th month), and gradually decreases as the number of months increased. The frequency of the first-time leak spikes again at the 12th month, and dramatically drops after the 15th month. The leak frequency stays relatively steady until the 33rd month. None of the study roofs report a first-time leak after 34 months.

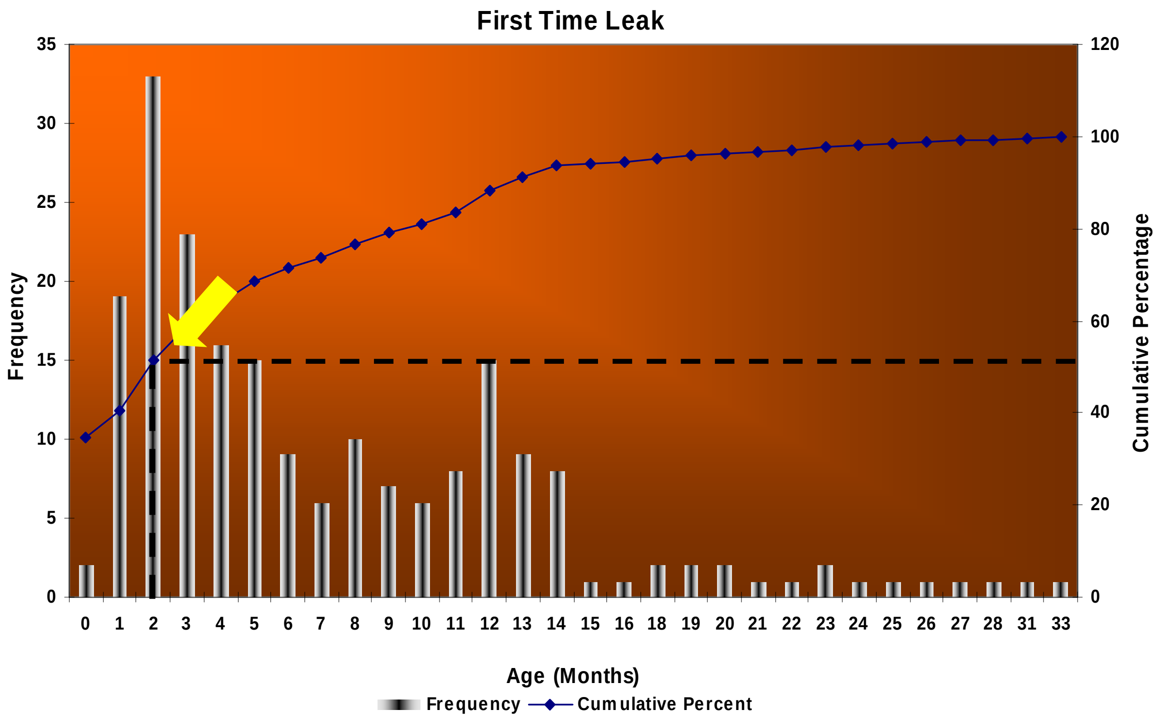

Figure 3.6 First-time Leak Frequencies

3. Material Types and Crew Names (Workmanship)

Approximately 86% of sample roofs are installed by the same roof installer, and nearly 100% of them are thermoplastic. A total of 43 sample roofs are installed by the other crews; of those, 60% and 40% of them are thermoplastic and thermoset, respectively. The ratio of total roofs installed by the primary installer to other crews in this dataset is 6:1. Table 3.14 summarizes the roof types and installation crews.

Table 3.14 Frequency of Membrane Types Classified by Roof Installers

Roof Crews	Material					
	Thermoplastic		Thermoset		Total	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Sole Installer	264	99	3	1	267	86
Other	26	60	17	40	43	14
Total	290	94	20	6	310	100

Table 3.15 Frequency of Leak Information Classified by Roof Installers

Workmanship (installers)	Leaks			No Leak			Total		
	Frequency	C%	R%	Frequency	C%	R%	Frequency	C%	R%
Other	40	**20**	*93*	3	**3**	*7*	43	**14**	*100*
Focused Roof installer	165	**80**	*62*	102	**97**	*38*	267	**86**	*100*
Total	205	**100**	*66*	105	**100**	*34*	310	**100**	*100*

As shown in Table 3.15, 80 percent of 'leak' and nearly 100% of 'no-leak' samples are installed by the focused crew. The number of 'leaks' is approximately one and a half times that of the 'no-leak' roofs. Ninety-three percent of roofs installed by other crews in this set of data are classified as 'leak'.

Table 3.16 Frequency of Leak Information Classified by Material Types

Material Types	Leaks			No Leak			Total		
	Frequency	C%	R%	Frequency	C%	R%	Frequency	C%	R%
Thermoset:EPDM	19	**9**	*95*	1	**1**	*5*	20	**6**	*100*
Thermoplastic:PVC,TPO	186	**91**	*64*	104	**99**	*36*	290	**94**	*100*
Total	205	**100**	*66*	105	**100**	*34*	310	**100**	*100*

Regarding the material type, 94%, or 290 roofs from the sample, are thermoplastic, as shown in Table 3.16. This material type also accounts for 91% of all 'leak' roofs and almost 100 percent of the 'no-leak' samples. Less than 10% of the entire 'leak' samples and only 1 percent of the 'no-leak' samples are thermoset membranes.

4. Store Locations (Weather Patterns)

The majority (59%) of study roofs are located in the Zone 2, or Zone 5. The rest of the stores are divided relatively evenly between Zones 1, 3 and 4, as shown in Table 3.17.

Table 3.17 Frequency of Leak Information Classified by Climate Zones

Climate Zone	**Leak**			**No Leak**			**Total**		
	Frequency	**C%**	**R%**	**Frequency**	**C%**	**R%**	**Frequency**	**C%**	**R%**
Zone1:less than 2,000 CDD and greater then 7,000 HDD	27	**13**		13	**12**		40	**13**	
			68			*33*			*100*
Zone2:less than 2,000 CDD and 5,500 - 7,000 HDD	62	**30**		33	**31**		95	**31**	
			65			*35*			*100*
Zone3:less than 2,000 CDD and 4,000 - 5,499 HDD	32	**16**		9	**9**		41	**13**	
			78			*22*			*100*
Zone4:less than 2,000 CDD and less than 4,000 HDD	32	**16**		14	**13**		46	**15**	
			70			*30*			*100*
Zone5:is 2,000 CDD or more and less than 4,000 HDD	52	**25**		36	**34**		88	**28**	
			59			*41*			*100*
Total	205	**100**		105	**100**		310	**100**	
			66			*34*			*100*

For the 'leak' sample, Table 3.17 reveals that a relatively similar number of 'leak' and 'no leak' stores are located in Zone 2 and Zone 5. The same number of 'leak' roofs (32) is found in Zone 3 and Zone 4. Zone 1, the coldest zone, has the smallest number of 'leak' samples.

For 'no-leak' samples, a relatively evenly spread of samples is found in Zone 2 and Zone 5, and in Zone 1 and Zone 4. The moderate climate region, Zone 3, has the least amount of 'no-leak' samples.

Considering the samples in the same climate zones, approximately 60-80% of them are classified as 'leak' roofs. The numbers of 'leak' samples in Zones 1, 2, and 4 are approximately twice the amount of 'no-leak' stores. A ratio of 1.5:1 of 'leak' to 'no-leak' roofs is found in Zone 5. The highest ratio (approximately 4:1) between 'leak' to 'no-leak' is found in Zone 3.

5. Installation Seasons

Forty-percent of the study roofs are installed in the fall. Twenty-three percent and 21% of the roofs are installed in the summer and spring, respectively. Only 16% of the study roofs are installed in the winter. Figure 3.7 presents the numbers of roofs installed per season.

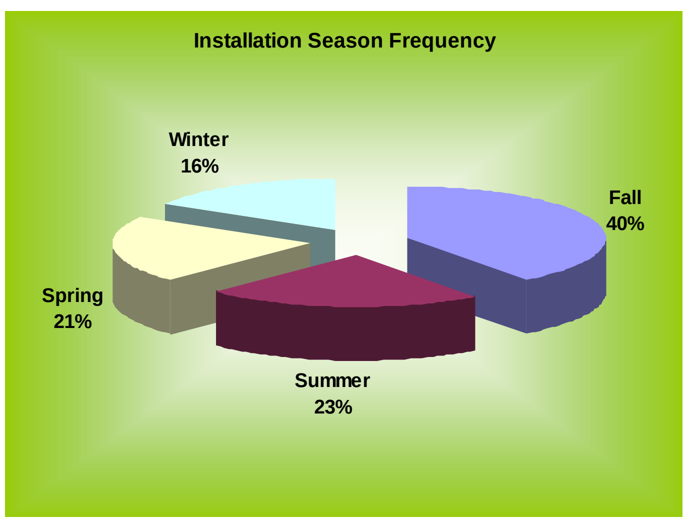

Figure 3.7 Numbers of Roofs Categorized by the Season Installed

Table 3.18 Frequency of Leak Information Classified by Roof Installation Seasons

Installation Seasons	Leaks			No Leak			Total		
	Frequency	C%	R%	Frequency	C%	R%	Frequency	C%	R%
Fall	73	**36**	*59*	50	**48**	*41*	123	**40**	*100*
Summer	50	**24**	*70*	21	**20**	*30*	71	**23**	*100*
Spring	48	**23**	*74*	17	**16**	*26*	65	**21**	*100*
Winter	34	**17**	*67*	17	**16**	*33*	51	**16**	*100*
Total	205	**100**	*66*	105	**100**	*34*	310	**100**	*100*

The highest numbers of 'leak' and 'no-leak' roofs in this dataset are represented in the 'fall' category. 'Summer' and 'spring' seasons have relatively equal numbers in 'leak' roofs, while an equal amount of 'no-leak' roofs are found in the 'spring and winter' categories. The fewest number of samples in both the 'leak' and 'no-leak' categories are roofs installed in the 'winter' season.

One hundred and twenty-three observed roofs are installed in the fall season; 60% of them are classified as 'leak'. The amount of 'leak' roofs installed in 'summer' and 'winter' categories is approximately two to three times the amount of 'no-leak' stores in the same category. The number of 'leak' samples installed in 'spring' season, however, is nearly three times its samples in the 'no-leak' category.

6. Local Settings

By nature of the structure and type of business, large space for store locations is needed. This is reflected in Table 3.19. The majority of the stores (82%) are located within urban or suburban areas, with open space ranging from 10 to 70%. Only 18% of the stores are located in either near vast open space, or dense areas (wooded or buildings).

Table 3.19 Frequency of Leak Information Classified by Stores' Local Settings

Local Settings	Leak			No Leak			Total		
	Frequency	C%	R%	Frequency	C%	R%	Frequency	C%	R%
Open > 70%	15	**7**	*58*	11	**10**	*42*	26	**8**	*100*
Open > 30% but < 70%	75	**37**	*72*	29	**28**	*28*	104	**34**	*100*
Open > 10% but < 30%	94	**46**	*63*	55	**52**	*37*	149	**48**	*100*
Open < 10%	21	**10**	*68*	10	**10**	*32*	31	**10**	*100*
Total	205	**100**	*66*	105	**100**	*34*	310	**100**	*100*

The majority of 'leak' (46%) and 'no-leak' (52%) samples are in 'open space between 10-30%' category. Thirty-seven percent of 'leak' samples have '30-70% open space'. Less than or equal to 10% of the samples are located where 'open space was more than 70% or less than 10%'.

The amount of 'leak' samples in the '30-70% open space' category is nearly three times the amount of the 'no-leak' sample. Only twice the amount of 'no-leak' roofs is found among samples in the 'open space 10-30% and less than 10%' category. Nearly 60% of all samples located where 'open space more than 70%' are classified as 'leak'.

7. Roof Penetrations

The number of roof-top units (RTU) is used to represent the number of roof penetrations. In the study sample, 87 percents of stores have 13 to 18 RTUs. The minimum RTU is 8 and maximum is 34, as shown in Table 3.20.

Table 3.20 Frequency of Leak Information Classified by Equipment Penetrations

Equipment Penetrations	Leak		No Leak		Total	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
8	0	0	1	1	1	0
12	5	2	0	0	5	2
13	**54**	**26**	**8**	**8**	**62**	**20**
14	**23**	**11**	**3**	**3**	**26**	**8**
15	**54**	**26**	**19**	**18**	**73**	**24**
16	**28**	**14**	**45**	**43**	**73**	**24**
17	**19**	**9**	**6**	**6**	**25**	**8**
18	**9**	**4**	**3**	**3**	**12**	**4**
19	4	2	1	1	5	2
20	2	1	1	1	3	1
21	1	0	0	0	1	0
22	2	1	3	3	5	2
23	2	1	0	0	2	1
24	0	0	3	3	3	1
25	0	0	1	1	1	0
26	0	0	2	2	2	1
27	1	0	0	0	1	0
29	0	0	1	1	1	0
30	0	0	1	1	1	0
31	0	0	3	3	3	1
32	0	0	1	1	1	0
33	0	0	3	3	3	1
34	1	0	0	0	1	0
Total	205	100	105	100	310	100

The samples with 13 and 15 RTUs have the highest frequency of ‘leaks’; these two categories together make up approximately half of all roof leaks, as shown in Table 3.20. Although the ‘16 RTU’ category has the second-highest frequency of ‘leak’ roofs, it also is the highest frequency category for ‘no-leak’. Very few samples have more than 18 RTUs and many of them are classified as ‘no-leak’.

8. Roof Age

In this study, 310 roofs installed between the years 2002 and 2005 are collected and used in the analysis. Every roof age, ranging from 0 to 40 months, is represented in this data set; the average age of roofs is 18 months. Approximately half of the study roofs are less than one-and-a-half-years old. The frequency of roof ages is shown in Figure 3.8.

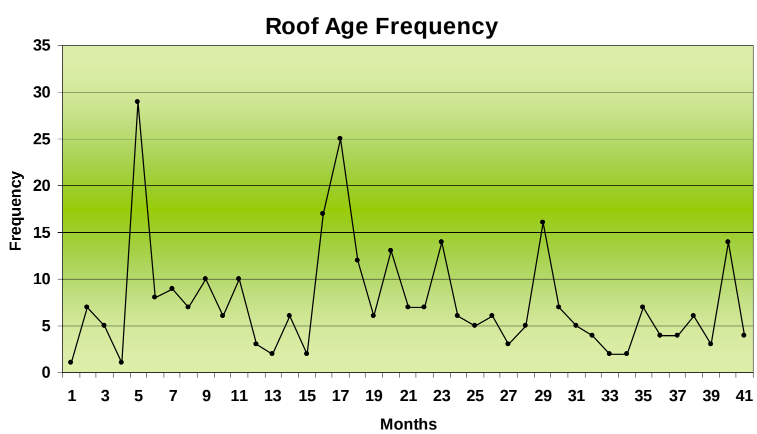

Figure 3.8 Frequency of Roof Age

Table 3.21 Frequency of Leak Information Classified by Roof Age (months)

Roof Age (month)	Leaks			No Leaks			Total		
	Frequency	C%	R%	Frequency	C%	R%	Frequency	C%	R%
0-6	11	5	18	49	47	82	60	19	100
7-12	19	9	50	19	18	50	38	12	100
13-18	47	23	69	21	20	31	68	22	100
19-24	44	21	85	8	8	15	52	17	100
25-30	37	18	88	5	5	12	42	14	100
31-36	23	11	100	0	0	0	23	7	100
37-42	24	12	89	3	3	11	27	9	100
Total	205	100	66	105	100	34	310	100	100

For the 'leak' group, the majority (62%) of sample roofs are in the range of '13-30' months, as shown in Table 3.21. Relatively equal numbers of 'leak' roofs are found in the age ranges of '31-36' and '37-42' months. Less than 15% of 'leak' stores are younger than one-year-old.

As expected, for the 'no-leak' group, 85% of the roofs are 0-18 months-old, with the highest frequency at 0-6 months. Approximately eight percent of 'no-leak' stores are older than two years. None of the 'no-leak' roofs are found in the age range of '31-36' months.

Table 3.21 also shows that, in the '0-6' month roof age range, the number of 'no-leak' store is five times higher than 'leak' stores. The numbers are split equally between 'leak' and 'no leak' stores in the age range of '7-12' months. For roofs older than one year, the ratios of 'leak' to 'no leak' ranges from 2:1 to 8:1. All of the samples in the age range of '31-36' months leak.

9. Roof Prototype

The area of study roofs ranges from 77,234 to 138,000 square feet. They typically can be divided into three main categories: '95K'; '102K'; and '115K'. The '115K' has the least amount in this sample in both the 'leak' and 'no-leak' categories, as seen in Table 3.22.

Table 3.22 Frequency of Leak Information Classified by Roof Types

Roof Prototype	Leak			No Leak			Total		
	Frequency	C%	R%	Frequency	C%	R%	Frequency	C%	R%
95K (< 99K)	98	**48**	*85*	17	**16**	*15*	115	**37**	*100*
102K (100K-109K)	64	**31**	*46*	76	**72**	*54*	140	**45**	*100*
115K (> 110K)	43	**21**	*78*	12	**11**	*22*	55	**18**	*100*
Total	205	**100**	*66*	105	**100**	*34*	310	**100**	*100*

Approximately a half of 'leak' sample stores are in '95K' categories. The '115K' has the fewest number of samples in the 'leak' category. Seventy-two percent of 'no-leak' stores are in the '102K' category. Only 17 and 12 percents of 'no-leak' samples are in the '95K' or '115K' categories, respectively.

Comparing samples in the same category, 85% and 78% of samples in '95K' and '115K' are 'leak' roofs. The '102K' category has almost an equal number of samples in the 'leak' and 'no-leak' categories.

3.8.2 Maintenance Record Data

1. Frequency of Foot Traffic on Roofs

On average, HVAC staff is on each study roof 1.09 times a month to either change filters or perform RTU repairs. The highest average is 2.17 times per month.

Fifty-one percent of all study roofs have an average of 1.01 to 1.50 HVAC staff on roofs per month. The second-highest frequency category, ‘0.51-1.00’ times on roof per month, makes up 30% of all samples. Three percent of the samples do not report any traffic on roofs; this can be because the roofs are brand new and maintenance is not yet needed. The rest of the frequency results can be seen in Figure 3.9 and Table 3.23.

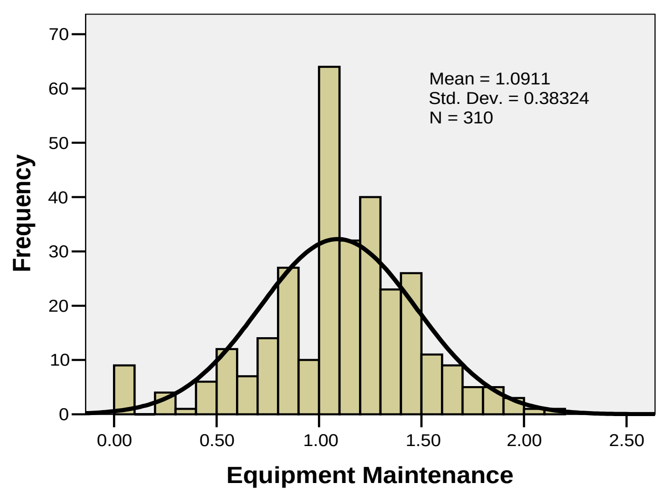

Figure 3.9 Average Frequency of Traffic on Roofs

Table 3.23 Frequency of Leak Information Classified by Average per Month Traffic on Roofs

Equipment Maintenance	Leak			No Leak			Total		
	Frequency	C%	R%	Frequency	C%	R%	Frequency	C%	R%
0.00	1	**0**	*11*	8	**8**	*89*	9	**3**	*100*
0.01-0.50	8	**4**	*40*	12	**11**	*60*	20	**6**	*100*
0.51-1.00	46	**22**	*49*	48	**46**	*51*	94	**30**	*100*
1.01-1.50	125	**61**	*80*	32	**30**	*20*	157	**51**	*100*
1.51-2.00	24	**12**	*83*	5	**5**	*17*	29	**9**	*100*
>2.00	1	**0**	*100*	0	**0**	*0*	1	**0**	*100*
Total	205	**100**	*66*	105	**100**	*34*	310	**100**	*100*

For the 'leak' sample group, 61% of the roofs have on average of 1.01-1.50 foot traffic occurrences per month. The '0.51-1.00' and '1.51-2.00', the second- and third-highest leak frequency categories, have only one-third and one-fifth the amount of roof samples in the '1.01-1.50' category, respectively. Both '0.00' and 'more than 2.00' times per month of the foot traffic categories each have only one 'leak' store. None of the 'no-leak' sample is found in the 'more than 2.00' category.

Comparing the samples in the same category, almost 90% of the sample roofs with no traffic are classified as 'no-leak', while 80% and 83% of samples in the '1.01-1.50' and '1.51-2.00' categories are classified as 'leak', respectively. Approximately an equal amount of 'leak' and 'no-leak' samples are found in the '0.51-1.00' category. Sixty-percent of roofs in the '0.01-0.50' foot traffic per month category are 'no-leak' stores.

2. Frequency of Inspection and Maintenance on Roof

On average, roofs are inspected about 0.04 times per month, or every two years (25 months). Almost 50% of the study roofs are not inspected at all during the study period. Thirty-nine percent of roofs are inspected between 0.001 and 0.100 times a month. Only 12% of roofs are inspected more than 0.100 times a month. The highest average inspection per month is 0.25 times a month or every four months. Figure 3.10 and Table 3.24 present the average frequency of roof inspection per month.

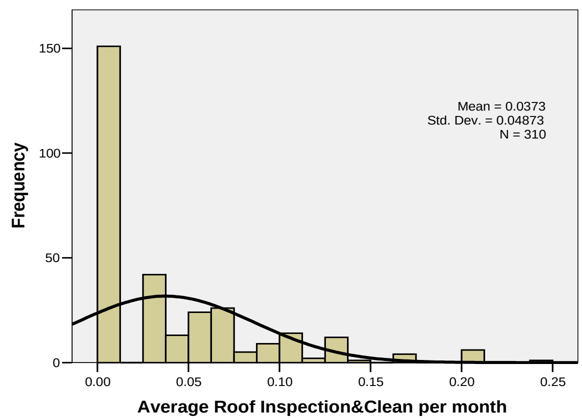

Figure 3.10 Average Frequency of Roof Inspection and Cleaning per Month

Table3.24 Frequency of Leak Information Classified by Average per Month Roof Inspection and Cleaning

Average Inspection per month	Leak			No Leak			Total		
	Frequency	C%	R%	Frequency	C%	R%	Frequency	C%	R%
0	76	**37**	*50*	75	**71**	*50*	151	**49**	*100*
0.001-0.100	104	**51**	*85*	18	**17**	*15*	122	**39**	*100*
0.101-0.200	25	**12**	*69*	11	**10**	*31*	36	**12**	*100*
0.201-0.300	0	**0**	*0*	1	**1**	*100*	1	**0**	*100*
Total	205	**100**	*66*	105	**100**	*34*	310	**100**	*100*

For the ‘leak’ sample group, the majority (51%) has between ‘0.001 and 0.100’ inspections per month; 37% do not have any inspection during the study period. Only 12% have more than 0.101 inspections per month. None of the store with inspections more than 0.201 times per month leaked.

Comparing the samples in the same category, nearly equal amounts of ‘leak’ and ‘no-leak’ samples are found in stores with no inspection. This finding contradicts industry opinion. One hundred and twenty-two samples have an average roof inspection between ‘0.001 and 0.100’ times per month; 85% of them are classified as ‘leak’ stores. Approximately 70% of stores with average inspection of ‘0.101-0.200’ times a month are ‘leak’ stores. Only one store has an average inspection more than 0.25 times per month and did not leak.

3. Frequency of Problems/Roof Repair (The Entire Study Period)

In this sample, the highest frequency of roof repairs per month is 0.40, or approximately every two months. However, 62% of the sample did not report any roof problems. The majority (24%) of reported problem roofs have on average of ‘0.01-0.20’ repairs per month. Only three percent of sample roofs have to be repaired on average every three months. The frequency can be seen in Figure 3.11 and Table 3.25.

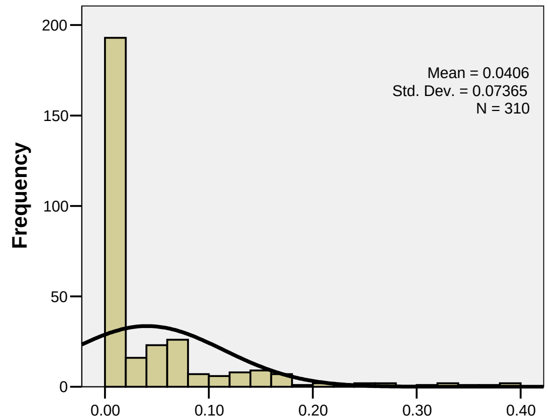

Figure 3.11 Average Frequency of Roof Repair per Month

Table 3.25 Frequency of Leak Information Classified by Average per Month Roof Repairs

Average Roof Repair per month	Leak			No Leak			Total		
	Frequency	C%	R%	Frequency	C%	R%	Frequency	C%	R%
0.00	108	**53**	*56*	85	**81**	*44*	193	**62**	*100*
0.01-0.10	63	**31**	*85*	11	**10**	*15*	74	**24**	*100*
0.11-0.20	21	**10**	*78*	6	**6**	*22*	27	**9**	*100*
0.21-0.30	6	**3**	*86*	1	**1**	*14*	7	**2**	*100*
>0.30	7	**3**	*78*	2	**2**	*22*	9	**3**	*100*
Total	205	**100**	*66*	105	**100**	*34*	310	**100**	*100*

For the 'leak' sample group, 53% of the entire 'leak' sample does not have any roof repairs. Thirty-one percent of the sample has an average of '0.01-0.10' repairs per month. Less than 10% has on average of more than 0.21 repairs per month.

Comparing the samples in the same category, 193 sample roofs do not have leak-related repairs during the study period; however, 56% of them leaked. Seventy-eight percent of the sample that have on average of '0.11-.0.20' and 'more than 0.30' roof repairs per month are classified as ‘leak’. Higher percentages (85% and 86%) of samples in the ‘0.01-0.10’ and ‘0.21-0.30’ categories are found to ‘leak’.

3.8.3 Conclusions

By interpretation and analysis of data on individual variables, it is difficult to clearly identify any relationship or tendency to leak, as presented in the previous sections. For example, it is not clear whether or not the store locations, considering climate zone and local settings information, have any correlation to roof leak incidences. The local weather, such as the amount of precipitation and wind, is also associated with the geographic location. However, they do not yield a similar trend of roof leaks. A statistical tool is then employed to give new insight into the relationship between identified variables and leaks.

3.9 Preliminary Data Analyses: Variable and Leak Relationship Analysis

The following analyses are performed to examine and identify relationships of each individual or group of variable and roof leaks. The information derived from these analyses, accompanied with other information, is used to manage and assist in a decision-making process during the model development.

3.9.1 Relationship between the Predictor and Individual Dependent Variables

For categorical variables, Pearson chi-square tests for relationships using ‘Crosstab’ command in SPSS are performed, while fitting univariable logistic regression is recommended for the continuous variable (Hosmer and Lemeshow 2000). Both Person’s chi-square and univariable logistic regression test whether the outcome and each predictor are independent. The predictor is in some way related to roof leaks when the statistical significant value is small enough (*p* less than .05) (Field 2005) and from now on it is called 'Selected Variables' or SV.

3.9.1.1 Categorical Univariable Analysis

Table 3.26 Categorical Univariate Pearson Chi-square Test Results

Categories		Pearson Chi-Square	Likelihood Ratio	Cramer's V	N of Valid Cases
Leaks * Installation Seasons	Value	4.843	4.863	0.125	310
	Df	3	3		
	Asymp. Sig. (2-sided)	.184	.182	.184	
Leaks * Climate Zones	Value	4.855	5.001	0.125	310
	Df	4	4		
	Asymp. Sig. (2-sided)	.303	.287	.303	
Leaks * Material Types	Value	7.956	10.449	0.160	310
	Df	1	1		
	Asymp. Sig. (2-sided)	**.005**	**.001**	**.005**	
Leaks * Workmanship (installers)	Value	16.122	20.014	0.228	310
	Df	1	1		
	Asymp. Sig. (2-sided)	**.000**	**.000**	**.000**	
Leaks * Local Setting	Value	3.142	3.161	0.101	310
	Df	3	3		
	Asymp. Sig. (2-sided)	.370	.367	.370	

Table 3.26 presents the results of the Pearson chi-square test for categorical variables in this study. From the table, it is clear that the 'Installation Seasons' do not have a significant effect (relationship) on whether or not roofs will leak (Pearson chi-square statistic (χ^2) = 4.843, *p* =.184). The Cramer's V statistic (V), measuring the strength of association, is .125 (Maximum = 1), and is not significant (*p* =.184). The results represent a low-to-no association with the possibility of happening by-chance between these two variables, and confirm the Pearson chi-square test result.

Using the same procedure, the following section summarizes the relation between each variable and leak incidences.

1) Leak and Climate Zone are not related, or Climate Zone does not effect whether or not roofs leak $\chi^2 = 4.855$, $p = .303$. Climate Zone has a low-to-no association to roof leaks with possibilities to happen by-chance, V = .125, $p = .303$.

2) Leak and Material Types are related $\chi^2 = 7.956$, $p < .01$. Material Types has a significant, low association to roof leaks with unlikely possibilities to happen by-chance V = .160, $p < .01$.

3) Leak and Workmanship (Crews) are significantly related $\chi^2 = 16.122$, $p < .001$. Workmanship has a highly significant, low-to-medium association to leak with unlikely possibilities to happen by-chance, V = .228, $p < .001$.

4) Leak and Local Settings are not related to roof leaks $\chi^2 = 3.142$, $p = .370$. The Local Settings has a low-to-no association to roof leaks, with possibilities to happen by-chance, V = .101, $p = .370$.

From the analysis, the categorical SVs are Material Type (MT) and Workmanship (WC).

3.9.1.2 Continuous Univariable Analysis

Table 3.27 Continuous Univariate Analysis Results

Variables	B	S.E.	Wald	df	Sig.	Exp(B)
Age (AG)	1.615	0.200	65.300	1	0.000	5.030
Roof Area (RA)	-0.207	0.121	2.928	1	0.087	0.813
Equipment Penetration (EP)	-0.713	0.157	20.543	1	0.000	0.490
Workmanship-Error (WE)	2.580	0.364	50.195	1	0.000	13.201
Temperature (TE)	-0.134	0.120	1.241	1	0.265	0.875
Dif. Temperature (DT)	-0.120	0.121	0.980	1	0.322	0.887
Dif. Max-Min (DD)	-0.150	0.120	1.566	1	0.211	0.860
Dif. Max-Min from normal (DDN)	0.064	0.125	0.262	1	0.609	1.066
Solar Radiation (SU)	-0.167	0.121	1.908	1	0.167	0.846
Wind Speed (WS)	0.033	0.125	0.071	1	0.790	1.034
Wind Max (WX)	-0.050	0.117	0.183	1	0.669	0.951
Precipitation (PR)	-0.011	0.120	0.009	1	0.926	0.989
Precipitation-snow (PS)	0.188	0.139	1.822	1	0.177	1.207
Relation Humidity (RH)	0.220	0.118	3.450	1	0.063	1.246
Equipment Maintenance (EM)	0.861	0.148	33.750	1	0.000	2.367
Roof Inspection-Cleaning (RI)	0.329	0.137	5.785	1	0.016	1.389
Roof Repair (RR)	0.452	0.165	7.534	1	0.006	1.572

Table 3.27 presents the results of continuous univariate logistic regression analysis. Eleven variables have Wald statistical significance (*Sig.*) > 0.05. The higher *Sig.* value, accompanied with the insignificance of the b-coefficients (less than 1), indicates that these variables may not make any significant contribution to the prediction of the outcome (leaks). However, Homer and Lemeshow suggest substituting the traditional *Sig.* < 0.05 with *Sig.* < 0.25 for multivariable model candidate screening purposes. They claim that, based on other researchers' work, the traditional *Sig.* level often fails to identify variables known to be important. However, using a higher level can potentially include variables that are of questionable importance at the model-building stage (Hosmer and Lemeshow 2000).

Following Homer and Lemeshow suggestion, the SVs from continuous variables are Age (AG), Roof Area (RA), Equipment Penetration (EP), Workmanship-Errors (WE), Different Max-Min Temperature (DD), Solar Radiation (SU), Precipitation-Snow (PS), Relative Humidity (RH), Equipment Maintenance (EM), Roof inspection (RI) and Roof Repair (RR).

3.9.2 Relationships Among Predictors (Multicollinearity)

A multicollinearity test is used to identify a correlation between predictor variables during modeling processes. High levels of collinearity increase the probability that a good predictor of the outcome will be found non-significant and be rejected from the model (a Type II error) (Field 2005) and can inflate the standard errors of the logit (effect) coefficients (Garson 2006).

Field, quoting Menard and Meyer, suggests that tolerant values less than 0.10 or a variance inflation factor (VIF) greater than 10 almost indicates a serious collinearity problem (Field 2005; Pallant 2005). From Table 3.28, only Temperature (TE), Solar Radiation (SU), and Climate Zone (CZ) have tolerance value less than 0.10 and the VIF more than 10, indicating the potential of multicollinearity.

Table 3.28 Multicollinearity Analysis Results

Coefficients	Collinearity Statistics	
	Tolerance	VIF
Roof Age (month)	0.451	2.217
Roof Area (sq ft)	0.756	1.324
Equipment Penetration	0.521	1.918
Workmanship (Avg installed errors)	0.522	1.914
Temperature	0.029	33.936
Different Temp from Normal	0.739	1.353
Different between Max & Min	0.244	4.100
Different Max & Min from Normal	0.647	1.546
Solar Radiation	0.066	15.100
Average Wind Speed	0.160	6.233
Average Wind Max	0.307	3.263
Average Precipitation-rains and others	0.309	3.231
Average Snowfall	0.163	6.132
Average Relative Humidity	0.247	4.054
Equipment Maintenance	0.565	1.770
Average Roof Inspection & Clean per month	0.739	1.352
Average Roof Repair per month	0.532	1.878
Installation Seasons	0.916	1.092
Climate Zones	0.073	13.777
Material Types	0.648	1.544
Workmanship (installers)	0.476	2.100
Local Setting	0.860	1.163
Dependent Variable: Leaks		

Further investigation is performed and the results also confirm that the collinearity exists. The problem's indicators are the combination of a much larger 'eigenvalue' and a massive 'condition index' compared to other predictor variables in the model, as presented in Appendix D. The variance proportion in the collinearity analysis table also shows the dependence between 'Solar Radiation' and 'Temperature' (70%, 59%), and between 'Climate Zone' and 'Temperature' (37%, 83%).

3.9.3 Conclusions

The Pearson's chi-square analysis shows that Workmanship (crews) $\chi^2(1) = 16.122$, p < 0.001, and Roof Material $\chi^2(1) = 7.956$, $p < .01$ have some relationship to roof leaks. Further analysis also reveals that only the main, 2-, and part of the 3-way interactions of categorical data significantly affect how the model fit the data. This finding is used as a decision factor during variable selection, as a part of the model creation process.

The univariate logistic regression results show some additional information regarding individual variable relationships with roof leaks. In this analysis, 11 out of 17 continuous variables are considered related and have a high potential to predict the leak incidence. The multicollinearity is tested and also confirms the existence of the problem in the dataset. These findings are used, with caution, in decisions regarding the model development in the next step.

CHAPTER 4

HISTORICAL MAINTENANCE DATA ANALYSIS: MODEL DEVELOPMENT

4.1 Purpose

This chapter describes the procedures used to develop and finalize the Historical Maintenance Data Analysis (HMDA) model in this dissertation. The chapter begins with a brief description of the logistic regression method. Then, the problems encountered during model development and the different starting model assumptions are narrated. The starting model results are described, followed by the initial model criteria and selection process. The final model improvement and the validation process are then presented in the last part of the chapter.

4.2 Logistic Regression Analysis

A brief description of logistic regression analysis is presented in the following sections. A detailed explanation is presented in Appendix E. This information is excerpted from a number of sources (Hosmer and Lemeshow 2000; chapter 12 in Tabachnick and Fidell 2000; chapter 5 and 6 in Field 2005; Garson 2006).

Binomial logistic regression is a multiple regression with a categorical binary outcome and continuous or categorical predictor variables. This distinguished feature, dichotomous outcomes, violates the linear relationship assumed by the linear regression. The logistic regression overcomes this problem by transforming the data into a logit variable (the natural log of the odds of the dependent occurring or not) using logarithmic transformation to express a non-linear relationship in a linear way (Field 2005).

The logistic analysis methods, for the most part, are the same as general principles used in linear regression (Hosmer and Lemeshow 2000). The goal of a logistic analysis, as any statistical model-building technique, is to find the best-fitting model to describe the relationship between the outcome and predictors. Not only can it determine the percent of variance in the dependent variable explained by the independents, the logistic can also rank the relative importance of independents, assess interaction effects, and describe the impact of covariate (Garson 2006).

4.3 Model Development

4.3.1 Problems Encountered

The explorative nature of the study and the lack of conclusive evidence results in a large number of variables potentially causing roof leaks. The number of independent variables identified not only pose a technical difficulty during model creation, but also a high and unrealistic need for more observation. Using the 10:1 case predictor ratio, the observation barely meets the minimum. The number of observed cases does not meet the stringent minimum requirement recommended by Garson and Peduzzi, Concato et al.

In addition, one principal assumption in this study is that the variables and their interactions contribute to roof leak problems. In some cases, the variables by themselves may not impact roofs; however, a combination with other variables can result in roof leaks. Therefore, this research tries not to eliminate any variable unless there is clear evidence to do so. The univariable analyses are somewhat helpful in eliminating some insignificant variables.

The traditional approach to statistical model building is to find the most parsimonious model that still explain the data (Hosmer and Lemeshow 2000). As a result, many statisticians do not recommend including many variables in the fitting model (Field 2005; Norusis 2005; Pallant 2005). More variables in the model can cause: 1) complicated and harder to generalize model; 2) increased risk of the estimated standard error (numerical unstable); and 3) dependency on the observed data (Hosmer and Lemeshow 2000).

In some disciplines, such as epidemiology, including all relevant variables regardless of their statistical significant is acceptable. The rationale for this approach is to provide complete control of any possible relationship within the collected data (Hosmer and Lemeshow 2000). This research follows this principle, since the focus is to explore all possibilities of leaks factors and leak incidences.

To overcome the unbalanced ratio problem, various assumptions and variable selection strategies are established and reflected in different starting models. Even with a moderate number of predictors, the variable selection process is still recommended (Shtatland, Cain et al. 2001). The preliminary models are then tested for the best performance (best fit to the data). The best-starting model is then used in the final model development.

The other problem experienced during model development is the lack of data, especially in the categorical variables. To overcome the problems, some of the data collected are re-grouped, in order to increase the data availability and model stability.

4.3.2 Assumptions and Variable Selection Criteria

The following sections present assumptions and variables selection criteria used in creating the different starting models.

4.3.2.1 Numbers of Predictors: Main Effect and Interactions

For the initial exploration, only main effect and two-way interactions are proposed as leak predictors. Higher-order interactions are not immediately included because:

1) There are limited numbers of observations to represent each interaction pattern. With 22 potential roof leak predictors, up to unrealistic 21-way interactions can be generated. As explained in the benefits and limitation sections in Appendix E, the goodness–of–fit loses its comparison power in this circumstance. Also, a limited number of observations will cause numerical instability in the analysis.

2) It can be very difficult and confusing, if not impossible, to interpret the results of higher-order interactions.

3) For explorative research, in general, an initial attempt is to understand relationships between the outcome and predictors in a simple form. After such a relationship is well-established, a more-complicated model can be pursued (Aiken and West 1991).

The following are assumptions regarding predictors in this research:

1. *Assumption One:* Only the main effect has influence on the roof leaks. In this assumption, the interaction effects among variables are not accounted for and the research's main assumption is violated. However, the model produces much more simple and stable results. The case and predictor ratio is satisfied.

2. *Assumption Two:* Roof leaks can be predicted from the main effect variables and the two-way interactions. This approach is based on the principal assumption that this study

starts with. This, however, poses a difficulty during model development and, therefore, variable selections processes need to be performed.

4.3.2.2 Variable Selection Processes: Univariable Analyses

The variable selection process begins with univariable analysis to identify relationships between the outcome (leaks) and individual predictor, as explained and preformed in Chapter 3: preliminary model analysis section. 'All identified variables' and 'selected variables (SV)' are tested in this study.

4.3.2.3 Variable Selection Processes: Automated Variable Selections

The power of computerized algorithms is employed for the automated model building. The purposeful variable selection, relying on expert experience, is suitable for a small number of variables and is not applicable in this situation.

There are many different algorithms for variable selections and removal available in SPSS. The maximum-likelihood computation is deemed the most-intensive and is recommended for the model development (Norusis 2005).

In the variable selection methods, many experts (Field 2005; Norusis 2005) claim that the 'Backward Stepwise Elimination' (BSE) is superior to 'Forward Stepwise Selection' (FSS) in an explorative setting research. However, not all approaches in this study can start with BSE due to the limitation of observations. To reduce potential errors in this process, a hybrid method is proposed. The analysis starts with the forward stepwise selection and is followed by a backward stepwise elimination to screen out all insignificant variables. By doing this, the most optimal subset of variables that contribute to leak problems can be obtained.

4.3.2.4 Level of Entry and Removal (Alpha Level)

Equally important to the automated method selection is the decision on the levels of entry and removal to eliminate insignificant variables in the stepwise process or 'alpha level (α)'. The consequences of these two values directly affect the number of variables to be included in the model. Traditionally, the significance for an entry level is 0.05 and 0.10 for a removal (system default) (Norusis 2005). However, Shtaland, Cain and Barton claim that this default setting is used without any supporting theory (Shtatland, Cain et al. 2001). One suggestion is to use a very small value, less than 0.05, as an alternative. Homer and Lemeshow, on the other hand, suggest using a less-stringent value in the range of 0.15 to 0.25 ((Hosmer and Lemeshow 2000; Tabachnick and Fidell 2000; Norusis 2005).

This research recognizes this dilemma and proceeds with a compromise approach. Two alpha levels 0.10, 0.15 and 0.25, 0.30 for variable selections are adopted, respectively. In general, the process always starts with a higher α (0.25, 0.30) to eliminate obvious insignificant variables. A higher α ensures that all significant and questionable variables are attained for further analyses. They are eliminated in the second round with a finer alpha level 0.10, 0.15, if they are proved unimportant. The system-default α is used in the main effect analysis without the filtering process.

4.3.3 Starting Model Creation Approaches

Eight preliminary models created from different combinations of assumptions and variable selection techniques are developed. Trials 1 to 4 are based on the assumption that only the main effect influences the roof leaks. The system-default alpha level is used in these trials. Trial 5 to 8 are based on the assumption that roof leaks can be predicted from the main effect variables and the two-way interactions; thus, a different α is used. The following sections summarize each trial procedure.

Trial 1: In this trial, all variables collected from the interviews are used as predictors and entered the equation simultaneously (direct logistic regression). Results reveal relations of predictors and the outcome in the simplest form.

Trial 2: In this trial, SV, obtained from univariable analysis are used as predictors; the rest of the analysis is the similar to Trial 1.

Trial 3: This trial starts by applying automated variable selection, BSE, to filter out unimportant variables collected during the interviews. The remaining significant main effects are then forced into the equation simultaneously.

Trial 4: In this trial, SV are used, rather than all the variables collected during the interviews. The rest of the analysis is the same as Trial 3.

Trial 5: All unimportant main effects are filtered out using BSE process. The remaining variables and their two-way interactions are screened out again using FSS regression. The variables from the previous step proceed to the final variable selection process, BSE with a finer alpha level, to ensure all unimportant variables are removed.

Trial 6: In this trial, only SV are use as the beginning predictors. The rest of the analysis process is the same as Trial 5.

Trial 7: This trial selects important variables from the pool of main effects and two-way interactions predictors using forward selection techniques. Then, BSE is performed to eliminate unimportant predictors that may have been included in the model during the variable selection. The benefits of this approach are that all variables and their interactions are included and tested at the same time. However, the drawback is that the model suffered from the low event per variable (EPV).

Trial 8: In this trial, only SV are use as the beginning predictors. The rest of the analysis process is the same as Trial 7.

The variables selection process in Trials 5 to 8 follow the alpha level principle described in the previous section. The bigger α is used at the beginning of the variable selection processes to include all potential variables. Then, a finer α is applied to weed out unimportant variables at the later stage. The following table summarizes the eight different trials.

Table 4.1 Eight Different Trials of Starting Models

Trial #	Interactions		Variable selection			Variables		Alpha Levels	
	Main effect	Main and 2-way interaction	None	FW	BW	All	selected	Default	Adjusted
Trial1	x		x			x		x	
Trial2	x		x				x	x	
Trial3	x				x	x		x	
Trial4	x				x		x	x	
Trial5		x		X	xx	x			X
Trial6		x		X	xx		x		X
Trial7		x		X	x	x			X
Trial8		x		X	x		x		X

Note: BW = Backward Stepwise, FW = Forward Stepwise, xx = running twice

4.4 Starting Model Results

4.4.1 Block 0

The result of the beginning model (Block 0 or model with only a constant) is the same in all trials; therefore, it is explained in this section only.

There are a total of 310 cases in this study, and all of them are included in the analysis. Roof leaks are coded “1”; and “0” is a code for roofs that do not leak. In this step, the model only fits the constant, and the SPSS predicts that all warehouse retail roofs leak at least one time within the first three year of their lives. This prediction is correct 205 times from the 310 cases (approximately 66%). The by-chance accuracy in this model (Block 0) is 55%. A full model is expected to have 25% improvement over this model (68.8%). The results of Block 0 are presented in Figure 4.1.

Case Processing Summary

Unweighted Cases		N	Percent
Selected Cases	Included in Analysis	310	100.0
	Missing Cases	0	.0
	Total	310	100.0
Unselected Cases		0	.0
Total		310	100.0

Dependent Variable Encoding

Original Value	Internal Value
No Leak	0
Leak	1

Iteration History

-2 Log likelihood	Coefficients Constant
399.068	.660

Classification Table

Observed		Predicted		
		Leaks		(%) Correct
		No Leak	Leak	
Leaks	No Leak	0	105	0.0
	Leak	0	205	100.0
Overall Percentage				65.9

Figure 4.1 Block 0 Results

4.4.2. Trial 1

Trial #	Input		Variable selection			Variables		Alpha Levels	
	Main effect	Main and 2-way interaction	None	FW	BW	All	selected	Default	Adjusted
Trial1	x		X			x		x	
Note: BW = Backward Stepwise, FW = Forward Stepwise									

Figure 4.2 Trial 1 Conditions

Results

Block 1: Method = Enter

Conditions: All main effects = 29 predictors (22 individual variables), α = 0.05, 0.10, EPV = 11:1 (meet the minimum requirement)

In this trial, the chi-square (χ^2) (268.985) show an improvement from the previous model (χ^2 = 399.068), and the change in the amount of information explained by the model is significant (p < .001). In other words, the model predicts leaks significantly better than it does without variables. The model accounts for 58-80% of the variables of roof leaks; roughly one-fifth of what causes roof leaks is still unknown. The model accurately classifies roof leaks up to 90.7%, which is better than 25% threshold of by chance accuracy (68.8%).

Only three predictors' logits (Age (AG), Workmanship (WE), and Roof repair (RR)) are significant (p < .001) in this trial. Results of the starting model from Trial 1 are presented in the following figures.

Omnibus Tests of Model Coefficients

	Chi-square	Df	Sig.
Model	268.985	29	.000

Model Summary

-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
130.083(a)	.579	.801

Classification Table

Observed		Predicted		
		Leaks		(%) Correct
		No Leak	Leak	
Leaks	No Leak	89	17	84.0
	Leak	12	193	94.1
Overall Percentage				90.7

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
AG	2.609	.482	29.336	1	.000	13.590
RA	-.221	.297	.554	1	.457	.801
EP	-.267	.419	.406	1	.524	.766
WE	4.917	.736	44.660	1	.000	136.592
TE	-1.507	1.461	1.064	1	.302	.222
DT	-.269	.283	.908	1	.341	.764
DD	-.733	.491	2.228	1	.136	.481
DDN	-.285	.251	1.281	1	.258	.752
SU	-.479	.944	.257	1	.612	.620
WS	-.680	.601	1.281	1	.258	.506
WX	.707	.460	2.358	1	.125	2.028
PR	-.623	.535	1.356	1	.244	.536
PS	.612	.642	.911	1	.340	1.845
RH	-.893	.536	2.770	1	.096	.410
EM	.481	.383	1.581	1	.209	1.618
RI	-.308	.264	1.357	1	.244	.735
RR	-1.692	.392	18.620	1	.000	.184
IS			4.970	3	.174	
IS(1)	.132	.729	.033	1	.856	1.141
IS(2)	.573	.787	.529	1	.467	1.773

Figure 4.3 Trial 1 Results

Variables in the Equation (Continued)

	B	S.E.	Wald	df	Sig.	Exp(B)
IS(3)	1.691	.882	3.677	1	.055	5.422
CZ			8.226	4	.084	
CZ(1)	-6.623	2.549	6.753	1	.009	.001
CZ(2)	-5.211	2.096	6.179	1	.013	.005
CZ(3)	-2.973	1.772	2.815	1	.093	.051
CZ(4)	-1.331	1.165	1.304	1	.254	.264
MT(1)	.397	1.329	.089	1	.765	1.488
WC(1)	.372	1.129	.108	1	.742	1.451
LS			5.993	3	.112	
LS(1)	-.603	1.358	.197	1	.657	.547
LS(2)	1.421	.961	2.187	1	.139	4.141
LS(3)	.258	.934	.076	1	.782	1.295
Constant	4.164	1.620	6.604	1	.010	64.328

Area Under the Curve

Area	Std. Error(a)	Asymptotic Sig.(b)	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.971	.008	.000	.956	.986

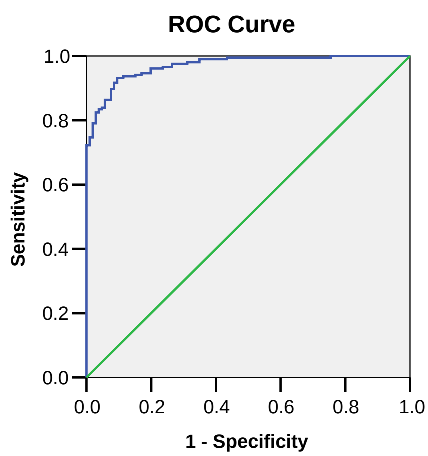

Figure 4.3 (Continued)

4.4.3. Trial 2

Trial #	Input		Variable selection			Variables		Alpha Levels	
	Main effect	Main and 2-way interaction	None	FW	BW	All	selected	Default	Adjusted
Trial2	x		x				x	x	
Note: BW = Backward Stepwise, FW = Forward Stepwise									

Figure 4.4 Trial 2 Conditions

Results

Block 1: Method = Enter

Conditions: All SV =13 predictors (13 individual variables), α = 0.05, 0.10, case: EPV = 24:1 (meet the minimum requirement)

In this trial, the chi-square (246.337) shows the improvement from the block 0 model (χ^2 = 399.068) with $p < .001$. The model predicts leaks significantly better than it did without variables. The predictors in this starting model account for approximately 55-76% of the variable of roof leaks. The model accurately classifies roof leaks up to 89.7%, better than 25% threshold of by chance accuracy (68.8%).

Out of 13 variables entered in this model, only three variables (Age (AG), Workmanship (WE), and Roof repair (RR)) have Wald statistics with chi-square distributions significantly different from zero ($p < .001$). Therefore, they make significant contribution to roof leaks. This trial yields results similar to Trial 1. The result of the starting model from Trial 2 is presented in the following figures.

Omnibus Tests of Model Coefficients

	Chi-square	df	Sig.
Model	246.337	13	.000

Model Summary

-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
152.731	.547	.757

Classification Table

Observed		Predicted		
		Leaks		(%) Correct
		No Leak	Leak	
Leaks	No Leak	87	19	82.1
	Leak	13	192	93.7
Overall Percentage				89.7

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
AG	1.879	.349	29.047	1	.000	6.548
RA	-.280	.246	1.294	1	.255	.756
EP	-.433	.339	1.628	1	.202	.649
WE	4.204	.589	50.977	1	.000	66.928
DD	-.146	.262	.312	1	.577	.864
SU	.047	.301	.024	1	.877	1.048
PS	.186	.293	.401	1	.527	1.204
RH	-.431	.265	2.646	1	.104	.650
EM	.233	.297	.617	1	.432	1.263
RI	-.215	.231	.865	1	.352	.807
RR	-1.343	.337	15.901	1	.000	.261
MT(1)	-.260	1.225	.045	1	.832	.771
WC(1)	.841	.956	.774	1	.379	2.318
Constant	1.979	.325	37.179	1	.000	7.234

Area Under the Curve

Area	Std. Error(a)	Asymptotic Sig.(b)	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.957	.011	.000	.935	.979

Figure 4.5 Trial 2 Results

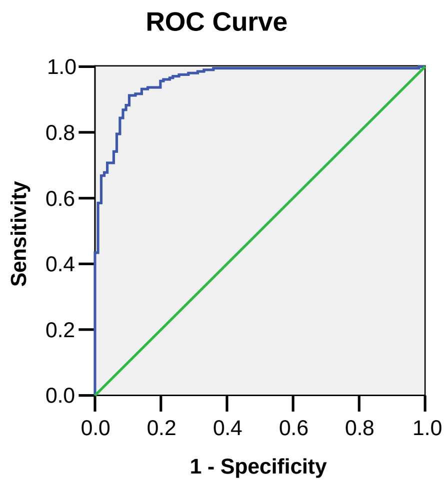

Figure 4.5 (Continued)

4.4.4. Trial 3

Trial #	Input		Variable selection			Variables		Alpha Levels	
	Main effect	Main and 2-way interaction	None	FW	BW	All	selected	Default	Adjusted
Trial3	x				x	x		x	
Note: BW = Backward Stepwise, FW = Forward Stepwise									

Figure 4.6 Trial 3 Conditions

Results

Block 1: Method = Backward Stepwise (Likelihood Ratio)

Conditions: All main effect = 29 predictors (22 individual variables), α = 0.05, 0.10, EPV = 11:1 (meet the minimum requirement but not prefer ratio for stepwise 50:1)

The backward stepwise eliminates 14 variables and maintains eight individual predictors in Step 15. No problems are found; all theses eight individual are used for the data fitting in the next step.

Block 2: Method = Enter

Conditions: Thirteen variables from block 1 = 13 predictors (8 individual variables), α = 0.05, 0.10, EPV = 24:1 (meet the minimum requirement)

After an examination, none of variables have numerical problems (standard error (SE) > 2, or a high change in odds (Exp B). The model accounts for 56-77% of the variable of roof leaks. The prediction accuracy is 89.4%, better than 25% threshold of by-chance accuracy (68.8%). Six out of eight variables in the model have coefficients significantly different from zero (Wald statistics significant different from zero ($p < .05$)). The results of the starting model from Trial 3 are presented in the following figures.

Omnibus Tests of Model Coefficients

	Chi-square	Df	Sig.
Model	253.846	13	.000

Model Summary

-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
145.222	.558	.772

Classification Table

Observed		Predicted		
		Leaks		(%) Correct
		No Leak	Leak	
Leaks	No Leak	88	18	83.0
	Leak	15	190	92.7
Overall Percentage				89.4

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
AG	2.506	.351	50.989	1	.000	12.258
WE	4.413	.617	51.088	1	.000	82.530
TE	-1.513	.633	5.702	1	.017	.220
DD	-.521	.259	4.037	1	.045	.594
RH	-.637	.274	5.424	1	.020	.529
RR	-1.587	.348	20.784	1	.000	.205
CZ			7.443	4	.114	
CZ(1)	-4.392	1.922	5.223	1	.022	.012
CZ(2)	-3.723	1.521	5.989	1	.014	.024
CZ(3)	-1.662	1.303	1.627	1	.202	.190
CZ(4)	-1.312	.879	2.225	1	.136	.269
LS			7.708	3	.052	
LS(1)	-1.513	1.163	1.692	1	.193	.220
LS(2)	1.057	.807	1.717	1	.190	2.878
LS(3)	-.024	.756	.001	1	.974	.976
Constant	4.014	1.223	10.770	1	.001	55.385

Figure 4.7 Trial 3 Results

Area Under the Curve

Area	Std. Error(a)	Asymptotic Sig.(b)	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.965	.009	.000	.947	.983

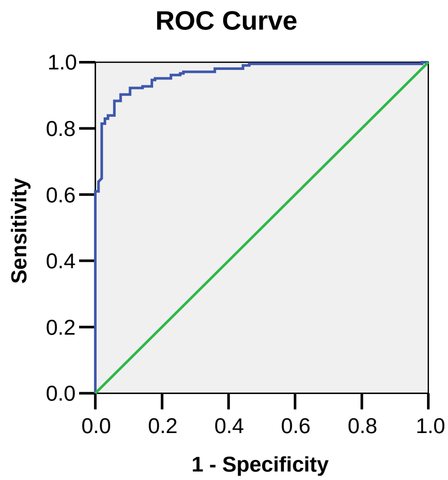

Figure 4.7 (Continued)

4.4.5. Trial 4

Trial #	Input		Variable selection			Variables		Alpha Levels	
	Main effect	Main and 2-way interaction	None	FW	BW	All	selected	Default	Adjusted
Trial4	x				x		x	x	
Note: BW = Backward Stepwise, FW = Forward Stepwise									

Figure 4.8 Trial 4 Conditions

Results

Block 1: Method = Backward Stepwise (Likelihood Ratio)

Conditions: All SV = 13 predictors (13 individual variables), α = 0.05, 0.10, EPV = 24:1 (meet the minimum requirement but not prefer ratio for stepwise 50:1)

The backward stepwise eliminates 10 variables and maintains three individual predictors in Step 11. No problems are detected; all of these three individuals are used for the data fitting in the next step.

Block 2: Method = Enter

Conditions: Three variables from block 1 = 3 predictors (3 individual variables), α = 0.05, 0.10, EPV = 103:1 (meet the minimum requirement)

After an examination, none of variables has SE > 2 or high Exp B, indicating numerical problems. The model accounts for 54%-74% of the variable of roof leaks. The prediction accuracy is 89.7%, better than 25% threshold of by chance accuracy (68.8%). All three variables (Age (AG), Workmanship (WE), and Roof Repair (RR)) have coefficient significantly different from zero ($p < .05$). The results of the starting model from Trial 4 are presented in the following figures.

Omnibus Tests of Model Coefficients

	Chi-square	Df	Sig.
Model	238.363	3	.000

Model Summary

-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
160.705	.535	.741

Classification Table

Observed		Predicted		
		Leaks		(%) Correct
		No Leak	Leak	
Leaks	No Leak	87	19	82.1
	Leak	13	192	93.7
Overall Percentage				89.7

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
AG	2.132	.286	55.624	1	.000	8.429
WE	4.037	.561	51.735	1	.000	56.669
RR	-1.364	.308	19.670	1	.000	.256
Constant	2.023	.310	42.707	1	.000	7.560

Area Under the Curve

Area	Std. Error(a)	Asymptotic Sig.(b)	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.956	.012	.000	.933	.979

Figure 4.9 Trial 4 Results

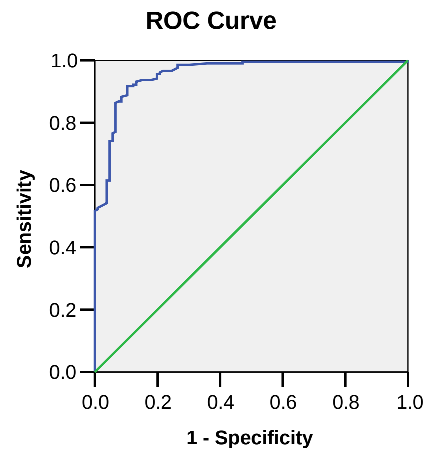

Figure 4.9 (Continued)

4.4.6. Trial 5

Trial #	Input		Variable selection			Variables		Alpha Levels	
	Main effect	Main and 2-way interaction	None	FW	BW	All	selected	Default	Adjusted
Trial5		x		x	xx	x			x
Note: BW = Backward Stepwise, FW = Forward Stepwise, xx = running twice									

Figure 4.10 Trial 5 Conditions

Results

Block 1: Method = Backward Stepwise (Likelihood Ratio)

Conditions: All main effect = 29 predictors (22 individual variables), α = 0.25, 0.30, EPV = 11:1 (meet the minimum requirement but not prefer for stepwise 50:1)

The SPSS eliminates four variables (Material Type (MT), Roof Installer (WC), Solar Radiation (SU), and Equipment Penetration (EP)), and ends up at Step 5 with 18 variables in the model (AG, RA, WE, TE, DT, DD, DDN, WS, WX, PR, PS, RH, EM, RI, RR, IS, CZ, LS). In this trial, a few variables can potentially be problems; Climate Zone (CZ) has SE > 2, and Workmanship (WE) has a high change in odd (Exp B). These 18 variables and the 2-way interactions among them are used as predictors for the next step of variable selection (forward stepwise).

Block 2: Method = Forward Stepwise (Likelihood Ratio)

Conditions: Eighteen variables from block 1 and their 2-way interactions = 312 predictors (171 individual variables), α = 0.25, 0.30, EPV = 1:1 (did not meet minimum requirement)

The SPSS warns of numerical problems in this process. A lack of enough frequencies for two-way interaction patterns and a very low ratio between observation cases and predictors can potentially be the problem. In this case, the variables in the final step are not automatically used as predictors for the next step. After an examination, the model in Step 13 was chosen out of 17 steps. The variables in this step are stable and are used for the last variable selection process. There are a total of 11 predictors in this step (AG, WE, RR, AG*RH, CZ*RA, LS*RA, WE*EM, WE*RR, CZ*PR, EM*RR, IS*RR).

Block 3: Method = Backward Stepwise (Likelihood Ratio)

Conditions: Twenty-one variables from block 2 = 21 predictors (11 individual variables), α = 0.10, 0.15, EPV = 15:1 (meet the minimum requirement but not prefer for stepwise 50:1).

The last step, backward stepwise, produces the same result as in Step 13 in the previous process. The total variables in final model are 11, and all individual variables have significant Wald statistic ($p < .05$). The WE, CZ*RA, and IS*RR variables have very high change in odds (Exp B). The model predicts leaks significantly better than it did without variables (χ^2 = 320.862, $p < .001$). The predictors in this starting model account for approximately 64%-89% of the variable of roof leaks. The model is accurately classified roof leaks up to 95.5%, better than 25% threshold of by chance accuracy (68.8%). The results of the starting model from Trial 5 are presented in the following figures.

Omnibus Tests of Model Coefficients

	Chi-square	Df	Sig.
Model	320.862	21	.000

Model Summary

-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
78.206	.644	.890

Classification Table

Observed		Predicted		
		Leaks		(%) Correct
		No Leak	Leak	
Leaks	No Leak	98	8	92.5
	Leak	6	199	97.1
Overall Percentage				95.5

Variables in the Equation

	B	S.E.	Wald	Df	Sig.	Exp(B)
AG	4.241	.826	26.384	1	.000	69.507
WE	10.995	1.961	31.443	1	.000	59579.959
RR	-4.521	1.846	5.998	1	.014	.011
AG by RH	-1.629	.690	5.583	1	.018	.196
CZ * RA			18.773	4	.001	
CZ(1) by RA	6.941	1.749	15.752	1	.000	1034.071
CZ(2) by RA	.787	.630	1.560	1	.212	2.197
CZ(3) by RA	5.678	1.522	13.916	1	.000	292.244
CZ(4) by RA	5.961	1.583	14.186	1	.000	387.908
LS * RA			20.275	3	.000	
LS(1) by RA	-5.434	1.409	14.869	1	.000	.004
LS(2) by RA	-4.854	1.227	15.659	1	.000	.008
LS(3) by RA	-2.900	.748	15.038	1	.000	.055
ZEM by WE	-2.326	.979	5.639	1	.018	.098
ZRR by WE	-1.380	.439	9.899	1	.002	.251
CZ * PR			9.504	4	.050	
CZ(1) by PR	-.229	.576	.158	1	.691	.795
CZ(2) by PR	-.959	.675	2.019	1	.155	.383
CZ(3) by PR	2.833	1.495	3.592	1	.058	17.001
CZ(4) by PR	2.656	1.093	5.905	1	.015	14.236

Figure 4.11 Trial 5 Results

Variables in the Equation (Continued)

	B	S.E.	Wald	Df	Sig.	Exp(B)
EM by RR	4.059	1.269	10.230	1	.001	57.901
IS *RR			17.928	3	.000	
IS(1) by RR	-2.722	1.710	2.536	1	.111	.066
IS(2) by RR	1.586	1.720	.851	1	.356	4.885
IS(3) by RR	3.920	1.899	4.259	1	.039	50.401
Constant	5.338	1.019	27.422	1	.000	208.053

Area Under the Curve

Area	Std. Error(a)	Asymptotic Sig.(b)	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.989	.004	.000	.981	.996

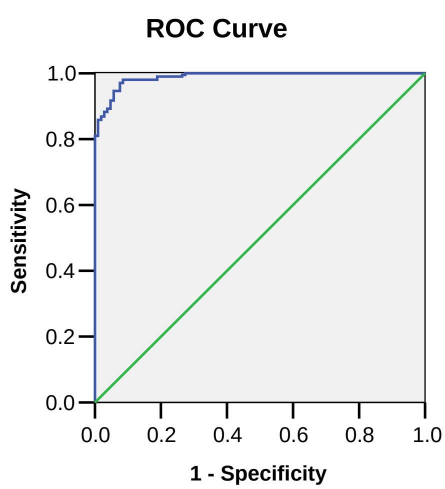

Figure 4.11 (Continued)

4.4.7. Trial 6

Trial #	Input		Variable selection			Variables		Alpha Levels	
	Main effect	Main and 2-way interaction	None	FW	BW	All	selected	Default	Adjusted
Trial6		x		x	xx		X		x
Note: BW = Backward Stepwise, FW = Forward Stepwise, xx = running twice									

Figure 4.12 Trial 6 Conditions

Results

Block 1: Method = Backward Stepwise (Likelihood Ratio)

Conditions: All 'selected variables' = 13 predictors (13 individual variables), α = 0.25, 0.30, EPV = 24:1 (meet the minimum requirement but not prefer for stepwise 50:1)

In this step, the backward stepwise eliminates six variables (SU, MT, DD, PS, EM, RI), and ended at Step 7. There are seven variables (AG, RA, EP, WE, RH, RR, WC); only one categorical predictor is included in this step. All these variables and the 2-way interactions between them are used in the next step.

Block 2: Method = Forward Stepwise (Likelihood Ratio)

Conditions: Seven variables from block 1 and their 2-way interactions = 28 predictors (28 individual variables), α = 0.25, 0.30, EPV = 11:1 (meet the minimum requirement but not prefer for stepwise 50:1)

The SPSS produces a total of 20 steps. However, after an examination, the variables in Step 14 are selected due to the lack of numerical problems; no variables have SE > 2 or extremely high Exp B. There are 14 variables in this step: AG, WE, RH, RR, AG*RH,

WC*AG, RA*WE, RA*RH, RA*RR, WC*RA, EP*WE, EP*RR, WE*RR, WC*RH. All of them are included in the last variable selection process.

Block 3: Method = Backward Stepwise (Likelihood Ratio)

Conditions: Fourteen variables from Block 2 = 14 predictors (14 individual variables), α = 0.10, 0.15, EPV = 22:1 (meet the minimum requirement but not prefer for stepwise 50:1).

The last step, BSE, produces the same result as the result in Step 14 from the previous step (forward stepwise). Total variables in final model are 14; of those, eight have significant Wald statistic ($p < .01$). Only WE has a high Exp B. The model predicts leaks significantly better than it does without variables ($\chi^2 = 292.136$, $p < .001$). The predictors in this starting model account for approximately 60-84% of the variable of roof leaks. The model accurately classifies roof leaks up to 92.6%, better than 25% threshold of by chance accuracy (68.8%). The results of the starting model from Trial 6 are presented in the following figures.

Omnibus Tests of Model Coefficients

	Chi-square	df	Sig.
Model	292.136	14	.000

Model Summary

-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
106.932	.609	.843

Classification Table

Observed		Predicted		
		Leaks		(%) Correct
		No Leak	Leak	
Leaks	No Leak	92	14	86.8
	Leak	9	196	95.6
Overall Percentage				92.6

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
AG	2.386	.513	21.640	1	.000	10.874
WE	7.214	1.061	46.266	1	.000	1357.724
RH	-1.198	.480	6.226	1	.013	.302
RR	-2.802	.705	15.805	1	.000	.061
AG by RH	-1.687	.765	4.867	1	.027	.185
WC(1) by AG	1.925	1.337	2.073	1	.150	6.857
RA by WE	1.276	.549	5.392	1	.020	3.581
RA by RH	-1.027	.543	3.581	1	.058	.358
RA by RR	-1.251	.722	2.999	1	.083	.286
WC(1) by RA	2.385	.933	6.531	1	.011	10.856
EP by WE	1.916	1.130	2.875	1	.090	6.794
EP by RR	-1.619	1.382	1.373	1	.241	.198
RR by WE	-.521	.228	5.235	1	.022	.594
WC(1) by RH	5.021	2.607	3.708	1	.054	151.557
Constant	3.396	.595	32.599	1	.000	29.853

Figure 4.13 Trial 6 Results

Area Under the Curve

Area	Std. Error(a)	Asymptotic Sig.(b)	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.979	.007	.000	.965	.993

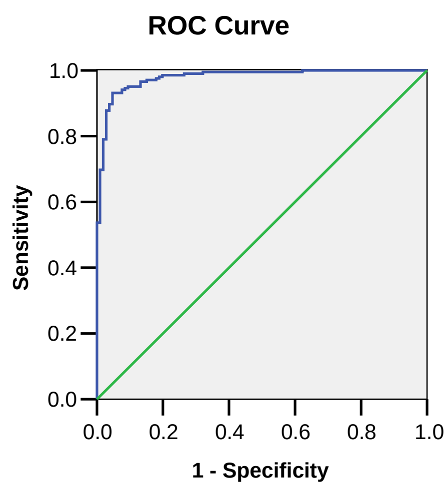

Figure 4.13 (Continued)

4.4.8. Trial 7

Trial #	Input		Variable selection			Variables		Alpha Levels	
	Main effect	Main and 2-way interaction	None	FW	BW	All	selected	Default	Adjusted
Trial7		x		x	x	x			x
Note: BW = Backward Stepwise, FW = Forward Stepwise									

Figure 4.14 Trial 7 Conditions

Results

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Conditions: All main effects and their 2-way interactions = 421 predictors (253 individual variables), α = 0.25, 0.30, EPV = 0.7:1 (did not meet minimum requirement)

The SPSS gives a warning notice of problems encountered in this trial because of the extremely low ratio between observed cases and numbers of predictors. A total of 18 steps are generated, but the last step fits perfectly and is disregarded. After an examination, variables in Step 13 are chosen for the last variable selection process. No variables in the step have SE >2, but a few variables have high Exp B or 95% confidential interval (CI). There are 11 variables in this step: AG, WE, RR, AG*RH, CZ*RA, LS*RA, WE*EM, WE*RR, CZ*SU, EM*RR, IS*RR

Block 2: Method = Backward Stepwise (Likelihood Ratio)

Conditions: Twenty-one variables from Block 1 = 21 predictors (11 individual variables), α = 0.10, 0.15, EPV = 15:1 (meet the minimum requirement but not prefer for stepwise 50:1).

This process yields the same set of variables as those variables obtained from the forward stepwise variable selection. A total of 21 variables are included in this step; only five of predictors do not have significant Wald statistic ($p < .05$). None of the variables have SE > 2, but WE has an extremely high Exp B. The model predicts leaks significantly better than it does without variables ($\chi^2 = 321.738$, $p < .001$). The predictors in this starting model account for approximately 65%-89% of the variables of roof leaks. The model accurately classifies roof leaks up to 95.5%, better than 25% threshold of by chance accuracy (68.8%). The results in this trial are similar to the results from Trial 5. The results of the starting model from Trial 7 are presented in the following figures.

Omnibus Tests of Model Coefficients

	Chi-square	Df	Sig.
Model	321.738	21	.000

Model Summary

-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
77.330	.645	.892

Classification Table

Observed		Predicted		
		Leaks		(%) Correct
		No Leak	Leak	
Leaks	No Leak	98	8	92.5
	Leak	6	199	97.1
Overall Percentage				95.5

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
AG	4.183	.785	28.428	1	.000	65.595
WE	10.875	1.948	31.182	1	.000	52850.366
RR	-4.407	1.820	5.864	1	.015	.012
AG by RH	-1.708	.562	9.227	1	.002	.181
CZ * RA			18.115	4	.001	
CZ(1) by RA	6.615	1.784	13.746	1	.000	746.153
CZ(2) by RA	.752	.666	1.277	1	.259	2.122
CZ(3) by RA	6.271	1.737	13.040	1	.000	529.192
CZ(4) by RA	5.832	1.554	14.091	1	.000	340.892
LS * RA			19.478	3	.000	
LS(1) by RA	-5.926	1.531	14.991	1	.000	.003
LS(2) by RA	-4.664	1.221	14.585	1	.000	.009
LS(3) by RA	-2.850	.747	14.567	1	.000	.058
WE by EM	-3.363	1.206	7.775	1	.005	.035
RR by WE	-1.319	.474	7.753	1	.005	.267
CZ * SU			8.937	4	.063	
CZ(1) by SU	.809	1.223	.438	1	.508	2.246
CZ(2) by SU	1.390	.677	4.208	1	.040	4.013
CZ(3) by SU	-2.377	.955	6.191	1	.013	.093
CZ(4) by SU	-.494	1.713	.083	1	.773	.610

Figure 4.15 Trail 7 Results

Variables in the Equation (Continued)

	B	S.E.	Wald	df	Sig.	Exp(B)
EM by RR	4.723	1.449	10.629	1	.001	112.492
IS * RR			17.217	3	.001	
IS(1) by RR	-3.421	1.701	4.046	1	.044	.033
IS(2) by RR	.998	1.807	.305	1	.581	2.712
IS(3) by RR	4.109	1.910	4.627	1	.031	60.872
Constant	5.899	1.092	29.176	1	.000	364.788

Area Under the Curve

Area	Std. Error(a)	Asymptotic Sig.(b)	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.989	.004	.000	.981	.997

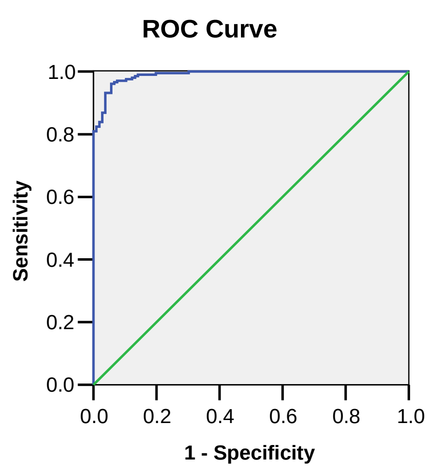

Figure 4.15 (Continued)

4.4.9. Trial 8

Trial #	Input		Variable selection			Variables		Alpha Levels	
	Main effect	Main and 2-way interaction	None	FW	BW	All	selected	Default	Adjusted
Trial8		X		x	x		x		x
Note: BW = Backward Stepwise, FW = Forward Stepwise									

Figure 4.16 Trial 8 Conditions

Results

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Conditions: All 'selected variables' and their 2-way interactions = 91 predictors (91 individual variables), α = 0.25, 0.30, EPV = 3:1 (did not meet the minimum requirement)

There is a warning due to a low ratio of variables and observed cases. A total of 36 steps are generated and declared a perfect fit at the last step. This step is then disregarded. After an examination, variables in Step 16 are selected for the next variable selection based on its overall conditions, no high SE or Exp B.

Block 2: Method = Backward Stepwise (Likelihood Ratio)

Conditions: Fifteen variables from Block 1 = 15 predictors (15 individual variables), α = 0.10, 0.15, EPV = 21:1 (meet the minimum requirement but not prefer for stepwise 50:1)

The last step uses BSE and produces the same result as in Step 16 of the previous step (forward stepwise). A total of 15 variables are in the final model, and only four do not have significant Wald statistic (p > .05). WE and EP*MT have some numerical problems, extremely high Exp B or SE > 2. The model predicts leaks significantly better than it did without variables (χ^2 = 296.439, p<.001). The predictors in this starting model account for approximately 61-85% of the variables of roof leaks. The model accurately classifies roof leaks up to 92.9%, better than 25% threshold of by chance accuracy (68.8%).

An additional trial is performed by eliminating the EP*MT, extremely high Exp B. There are no changes in the result (other variables still had a high SE and Exp B). The results of the starting model from Trial 8 are presented in the following figures.

Omnibus Tests of Model Coefficients

	Chi-square	Df	Sig.
Model	296.439	15	.000

Model Summary

-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
102.629	.614	.850

Classification Table

Observed		Predicted		
		Leaks		(%) Correct
		No Leak	Leak	
Leaks	No Leak	95	11	89.6
	Leak	11	194	94.6
Overall Percentage				92.9

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
AG	1.949	.403	23.397	1	.000	7.023
WE	8.044	1.333	36.426	1	.000	3116.480
RR	-3.013	.666	20.471	1	.000	.049
WC(1) by AG	4.649	1.655	7.886	1	.005	104.439
RA by EP	-.746	.402	3.435	1	.064	.474
RA by WE	2.349	.580	16.394	1	.000	10.479
RA by RH	-1.356	.450	9.061	1	.003	.258
RA by RR	-1.754	.550	10.156	1	.001	.173
MT(1) by EP	8.529	4.694	3.302	1	.069	5059.058
WE by EM	-2.230	.821	7.384	1	.007	.108
WE by RR	-.842	.255	10.893	1	.001	.431
DD by RR	-.914	.368	6.169	1	.013	.401
SU by RI	-.621	.347	3.210	1	.073	.537
EM by RR	1.785	.741	5.798	1	.016	5.961
RI by RR	.313	.227	1.907	1	.167	1.368
Constant	3.787	.708	28.615	1	.000	44.105

Figure 4.17 Trial 8 Results

Area Under the Curve

Area	Std. Error(a)	Asymptotic Sig.(b)	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.982	.006	.000	.969	.994

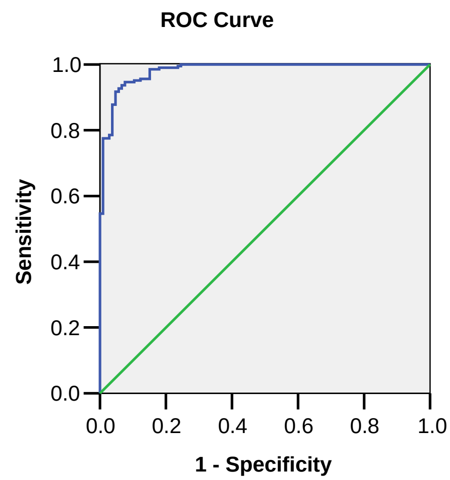

Figure 4.17 (Continued)

4.5 Starting Model Selection

4.5.1 Starting Model Selection: Criteria

The criteria used to select the best starting model are:

1. *R-square* (Cox and Snell's R-Square (C&S-R^2) and Negelkerke's R-square (N-R^2))*:* This is explained in Appendix E: logistic regression sections.

2. *Classification Percentage:* This is also explained in Appendix E.

3. *The Bayesian Information Criteria (BIC):* BIC is used to select the best model among several competing models. Essentially, the BIC is designed to choose a model that describes the data adequately without using too many parameters. The model with the smallest BIC value is considered to be the best model.

4. *Area Under the Receiver Operating Characteristic (ROC):* This measure describes the classification accuracy of the model. The area under the ROC curve, ranging from 0 to 1, provides a measure of the model's ability to discriminate between cases that leaks and the cases that did not leak. The model with ROC value closer to one is preferred.

5. *The Complexity or Simplicity of the Model:* The overall complexity of the model is also used as a measure to select the best initial model. With the relatively similar values in BIC, ROC, and model prediction accuracy, the fewer numbers of predictors in the final model are considered better. The overall values in each predictor are also examined. Some indications of model problems are: 1) a standard error (SE) of the logits coefficient higher than 2, indicating numerical problems (Schwab 2006); and 2) an extremely high value in the change in odds (Exp B), upper or lower limit of the 95% confidential interval.

Table 4.2 Starting Model Result Summary

Model	n	Var.	EPV	Model Summary			Hosmer & Lemeshow			Class. (%)	BIC	ROC
				-2 Log	C&S R^2	N R^2	X^2	df	*p*			
Trial1	310	29	11	130.08	0.58	0.80	9.65	8	0.29	90.7	202.33	0.97
Trial2	310	13	24	152.73	0.55	0.76	5.60	8	0.69	89.7	185.12	0.96
Trial3	310	13	24	145.22	0.56	0.77	5.53	8	0.70	89.4	177.61	0.97
Trial4	310	3	103	160.71	0.54	0.74	18.18	8	0.02	89.7	168.18	0.96
Trial5	310	21	15	78.21	0.64	0.89	1.80	8	0.98	95.5	130.53	0.99
Trial6	310	14	22	106.93	0.61	0.84	4.18	8	0.84	92.6	141.81	0.98
Trial7	310	21	15	77.33	0.65	0.89	2.91	8	0.94	95.5	129.65	0.99
Trial8	310	15	21	102.63	0.61	0.85	10.65	8	0.22	92.9	140.00	0.98

4.5.2 Starting Model Selection: Conclusions

From the summary table (Table 4.2) and the criteria described, Trial 7 is considered the best with the lowest BIC, and highest classification percentage, R-square, and ROC curve. However, the model also produces an extremely high SE and many unstable variables with a low event per variables (EPV). The second, third or fourth to the best model, Trials 5, 8, 6 also have similar problems. These models are derived from using main effect and their two-way interaction as input predictors.

The next-best model, Trial 4, is chosen due to its simplicity and relatively similar classification accuracy, R-square and ROC curve with other trials derived from using only main effect variables as inputs. It, however, has the best BIC value.

Trials 4 and 7 are chosen to be developed into the final model.

4.6 Starting Model Improvement

Two approaches to improve the final model are described in this section. They are: 1) examine and potentially eliminate outliners; and 2) add additional terms (increase the complexity).

4.6.1 Outliers

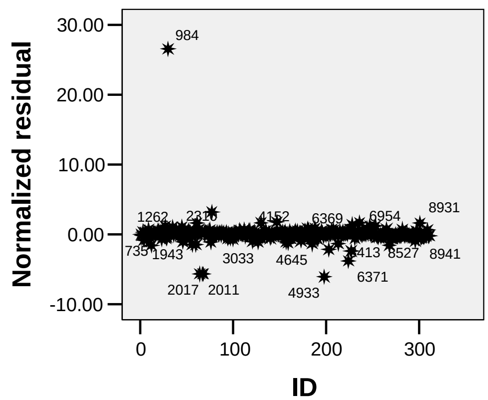

Figure 4.18 Trial 4 Outlier Plots (Normalized Residual)

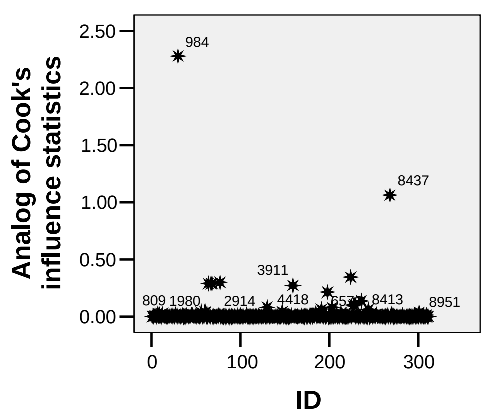

Figure 4.19 Trial 4 Outlier Plots (Cook's Distance)

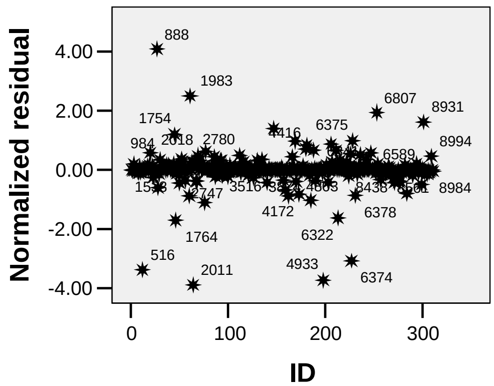

Figure 4.20 Trial 7 Outlier Plots (Normalized Residual)

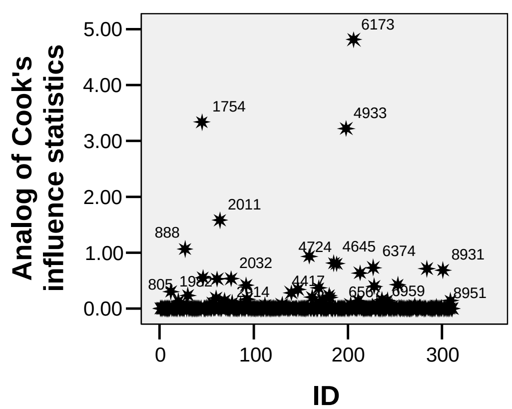

Figure 4.21 Trial 7 Outlier Plots (Cook's Distance)

The residual graphs (Figure 4.18-4.21) show that Trials 4 and 7 had eight and seven cases of potential outliers, respectively. The outliers are defined as cases having standard residual for dependent variable (ZRE) or Cook's distance (COO) higher than 3.0 and 1.0, respectively. A high ZRE indicates the poorly fit spot of the model and are potential outliers. The Cook's distance assesses the influence of individual cases on the model. Any value greater than 1 indicates a possible influence case. Table 4.3 presents the summary results after eliminating potential outliers in Trials 4 and 7.

Table 4.3 Summary of Trial 4 and 7 after Eliminating Outliers

Model	n	Var.	EPV	Model Summary			Hosmer & Lemeshow			Class. (%)	BIC	ROC
				-2 Log	C&S R^2	N R^2	X^2	df	p			
Trial4	303	3	101	92.82	0.62	0.86	4.45	8	0.81	92.1	100.26	0.99
Trial7	304	21	14	29.12	0.69	0.96	0.59	8	1.00	98.4	81.26	1.00

After eliminating the eight potential outliers in Trial 4, the model's prediction accuracy does not improve much (less than 2 %). However, the Homer and Lemeshow goodness-of-fit test significantly improves the accuracy, as well as the -2 log likelihood. One drawback of this improvement is that the change in odds (Exp B) increases dramatically.

For Trial 7, after eliminating seven potential outliers, the model still has the best prediction and lowest BIC. Nevertheless, the existing problems seem to increase their severity. Many variables have extremely high Exp B, upper and lower limit of 95% confidential interval, and standard error. Trial 7 is abandoned due to these problems; only Trial 4 is used for the final model development.

4.6.2 Interactions

The higher interaction orders (two- and three-way interaction) are added to Trial 4 and tested for the model's performance improvement. As presented in Table 4.4, both two- and three-way interactions marginally improve the original model. The three main effects are then used as predictors in the final model.

Table 4.4 Trial 4 Interaction Term Testing Results

Model Descriptions	Variables input	Var.	Model Summary			Class. (%)	BIC
			-2 Log	C&S R^2	N R^2		
Final Model	AG, WE, RR	3	92.82	0.62	0.86	92.1	100.26
Final + 3 (2-way)	AG, WE, RR, AG*WE, AG*RR, WE*RR	6	89.11	0.62	0.87	92.4	104.00
Final+ 3 (2-way) + 1 (3-way)	AG, WE, RR, AG*WE, AG*RR, WE*RR, AG*WE*RR	7	88.17	0.62	0.87	92.1	105.54
Final + 1 (2-way)	AG, WE, RR, AG*WE	4	90.24	0.62	0.86	92.1	100.16
Final + 1 (2-way)	AG, WE, RR, AG*RR	4	90.26	0.62	0.86	92.1	100.18
Final + 1 (2-way)	AG, WE, RR, WE*RR	4	90.95	0.62	0.86	92.1	100.87
Final + 1 (3-way)	AG, WE, RR, AG*WE*RR	4	92.46	0.62	0.86	92.1	102.39
Final + 2 (2-way)	AG, WE, RR, AG*WE, AG*RR	5	89.20	0.62	0.87	92.4	101.61
Final + 2 (2-way)	AG, WE, RR, AG*WE, WE*RR	5	89.60	0.62	0.87	92.1	102.01
Final + 2 (2-way)	AG, WE, RR, AG*RR, WE*RR	5	89.95	0.62	0.87	92.4	102.36
Final+ 1 (2-way) +1 (3-way)	AG, WE, RR, AG*WE, AG*WE*RR	5	90.23	0.62	0.86	92.1	102.64
Final+ 1(2-way) +1 (3-way)	AG, WE, RR, AG*RR, AG*WE*RR	5	89.13	0.62	0.87	92.4	101.54
Final + 1 (2-way) +1(3-way)	AG, WE, RR, WE*RR, AG*WE*RR	5	90.93	0.62	0.86	92.1	103.34

4.6.3 Extra Testing

The researcher is specifically interested in whether or not environmental factors (temperature, precipitation, etc.) contribute to roof leak incidence. Therefore, an extra logistic regression trial is performed. The omission of the maintenance information (RI, RR) is assumed, since such information is not widely available. Results show that none of the additional trials has a superior performance than the final model, which contains three variables. The trial results are shown in Appendix F.

The final mathematical model showing relations between roof leaks and predictors is presented in the following equation:

$$y = 3.65 + 3.36 \text{ (roof age)} + 7.12 \text{ (workmanship)} - 2.39 \text{ (roof repair)} \qquad \text{(Equation 4.1)}$$

The probability of roof leaks can be predicted using the following equation:

$$\text{Probability (leaks)} = \frac{1}{1 + e^{-(3.65 + 3.36(AG) + 7.12\,(WE) - 2.39\,(RR)}} \qquad \text{(Equation 4.2)}$$

4.7 Validation

4.7.1 Internal Validation

As described previously in the research methodology chapter, the k-folder cross validation is used for the internal validation purpose. The k = 5 and 10 are used to test the model robustness (Anonymous 2004; Gutierrez-Osuna 2006; Yuan 2006). The k = 5 is run three times, while the k = 10 is performed only one time. Each time, new random numbers are generated and divided into 5 or 10 subsets. The result of the internal validation show that k = 10 produces less than 7.8% misclassified; the k = 5 misclassification rates are 7.7%, 7.6%, and 7.8%, respectively. The average estimated generalization errors are relatively similar to the misclassified numbers in the full model in all cases. The test results confirm that the developed model is a good fit for the data. Table 4.5 shows one of the results from the internal validation. Appendix G shows all the internal validation results.

Table 4.5 5-Folder Cross Validation

Model#	Training case	Hold out case	Training accuracy (%)	Hold out accuracy (%)
5A	245	58	92.7	93.1
5B	248	55	92.7	87.3
5C	244	59	93.0	89.8
5D	245	58	92.2	93.1
5E	230	73	90.9	94.5
Average Accuracy			92.3	91.6
Average Misclassify			7.7	8.4

4.7.2 External Validation

The second dataset obtained from a different source is used in the external validation process. These data contain similar information, roof types and structure, as used in the data training in the final model.

The raw data goes through the same data preparation and are organized into a tabular form. All relevant information, such as the age of the roof (AG), the average problems encountered per month within the first year of roof's lives (WE), and the average problems experienced per month, not including leak problems (RR), are captured. The predictors in Equation 4.1 are then substituted by the ready-to-use data.

The result yielded from this equation is the linear regression of the equation in each observed case. These values are then transformed using natural log to predict the probability of leaks or no leak for each case using Equation 4.2.

To predict roof leaks, the cutting point of 0.50 is used. If a probability of a specific validated case is less than 0.50, then the model predicts the roof does not leak (0). On the other hand, if the probability is more than 0.50, then the model predicts roof leaks within the first three year of roof life. The result of linear regression values of each case is found in Appendix H.

The predicted leak derived from the model and the actual roof leaks are then compared. The summary of the comparison between the prediction and actual leaks in the second set data is presented in Table 4.6.

Table 4.6 Summary of Predicted and Actual Leaks in Second Dataset

ID	Second set		Actual	Misclassified
	Probability	Predicted		
1	0.99923	Leak	Leak	No
2	0.00003	No Leak	No Leak	No
3	0.00839	No Leak	Leak	Yes
4	0.00839	No Leak	Leak	Yes
5	0.03052	No Leak	Leak	Yes
6	0.51694	Leak	Leak	No
7	0.07826	No Leak	Leak	Yes
8	0.00358	No Leak	Leak	Yes
9	0.23651	No Leak	Leak	Yes
10	0.54484	Leak	Leak	No
11	0.99829	Leak	Leak	No
12	0.99998	Leak	Leak	No
13	1.00000	Leak	Leak	No
14	0.01164	No Leak	Leak	Yes
15	0.89068	Leak	Leak	No
16	0.00770	No Leak	No Leak	No
17	0.99995	Leak	Leak	No
18	0.99678	Leak	Leak	No
19	0.64763	Leak	Leak	No
20	0.80075	Leak	Leak	No
21	0.99915	Leak	Leak	No
22	0.99994	Leak	Leak	No
23	0.55587	Leak	Leak	No
24	0.00020	No Leak	No Leak	No
25	0.99820	Leak	Leak	No
26	0.98721	Leak	Leak	No
27	0.65991	Leak	Leak	No
28	0.99996	Leak	Leak	No
29	0.60234	Leak	Leak	No

Table 4.6 (Continued)

ID	Second set		Actual	Misclassified
	Probability	Predicted		
30	0.05749	No Leak	Leak	Yes
31	1.00000	Leak	Leak	No
32	0.55587	Leak	Leak	No
33	0.00036	No Leak	Leak	Yes
34	0.97995	Leak	Leak	No
35	0.00002	No Leak	No Leak	No
36	0.89378	Leak	Leak	No
37	0.05006	No Leak	Leak	Yes
38	0.99360	Leak	Leak	No
39	0.99848	Leak	Leak	No
40	0.88343	Leak	Leak	No
41	0.99997	Leak	Leak	No
42	0.98310	Leak	Leak	No
43	0.68865	Leak	Leak	No
44	0.95648	Leak	Leak	No
45	0.40684	No Leak	Leak	Yes
46	0.98813	Leak	Leak	No
47	0.96198	Leak	Leak	No
48	0.89134	Leak	Leak	No
49	0.99904	Leak	Leak	No
50	0.97850	Leak	Leak	No
51	0.99800	Leak	Leak	No
52	0.99949	Leak	Leak	No
53	0.99989	Leak	Leak	No
54	0.99557	Leak	Leak	No
55	0.99989	Leak	Leak	No
56	1.00000	Leak	Leak	No
57	1.00000	Leak	Leak	No
58	0.99999	Leak	Leak	No
59	1.00000	Leak	Leak	No
60	1.00000	Leak	Leak	No

The model accuracy prediction rate for the second dataset is 82%, compared to the prediction rate in the original data set (92%). The difference between the two is 10%, which is not severely dropped from the training/full model. This evidence shows that the model developed is accurate enough to predict the leak incidence in the second dataset (Field 2005).

CHAPTER 5

ROOF SERVICE LIFE PREDICITON:

'FACTOR METHOD' ANALYSIS

5.1 Purpose

This chapter presents the results of Roof Service Life Prediction (RSLP), which investigates the relationship between the first-time leak and service life prediction using the 'Factor Method'. In this chapter, each factor class is explained, variables in the context of roof assemblies are then interpreted and identified, and rating values are assigned. The results of 56 trials of Pearson's correlation analysis are presented in the second part of this chapter.

5.2 Variable Identification

According to the 'Factor Method' proposed in ISO 16868, the followings seven factor classes directly impact the building material or component service life.

Factor Class A:	Inherent Performance Level (Quality of Components)
Factor Class B:	Design Level
Factor Class C:	Work Execution Level
Factor Class D:	Indoor Environment
Factor Class E:	Outdoor Environment
Factor Class F:	Usage Condition (In-Use Conditions)
Factor Class G:	Maintenance Level

In the current situation, little reference in-use condition information is widely available. To overcome this deficiency, physical reasoning and subjective interpretation is performed to identify roof variables in each factor class. This study is intended to be a proof-of-concept and to present an initial investigation of this approach. When more accurate knowledge is available, the study can be then improved.

The variable rating levels and assigned values are presented in the following section. The detailed descriptions of each factor class are directly excerpted from ISO 16868-8.

5.2.1 Factor Class A: Inherent Performance Level

Description:

This factor represents the grade of the supplied component. A detailed description of the material or component is provided below.

Interpretation:

The grade of component is perceived as a limitation in the material's performance or weak-points inherent in the system. These constraints may increase a chance of premature failures. According to the expert interviews, the following are factors that potentially increase the chance of roof leak (failures) in single-ply roof materials or systems.

1. Material: reinforcement or no reinforcement

More problems are reported with the un-reinforced single-ply membranes than reinforced membranes. For example, in the TPO case, un-reinforced membrane is a major reason for material shatter in TPO (Griffin and Fricklas 1995). EPDM membranes are also assumed to yield the same result.

2. Attachment systems, especially in field seams.

According to the project pinpoint report (Cullen 1993), lap/seam problems are the number one problem found in most single-ply membranes. As with the nature of single-ply roof assembly, the system is, in essence, only as good as the strength and quality of the adhesion techniques. Fewer field seam problems are reported on TPO. The thermoplastic nature required heat weld and, in this case, is deemed superior.

3. System weak points: Numbers of penetrations and foot traffic.

Two well-known critical weak-points of single-ply membranes are: 1) less resistance to punctures, especially from heavy foot traffic; and, 2) unsuitable for high numbers of roof top equipment penetrations (HVAC roof top units or ventilation pipes). Therefore, roof assemblies with fewer numbers of penetrations or foot traffic are assumed to have less roof problems. Traffic frequency is not presented in this factor because it is also reflected in the usage condition (Factor F). Table 5.1 shows the condition level of each sub-factor in this factor class.

Table 5.1 Variables Represented Factor Class A

Value (ISO)	0.9	0.95	1.0	1.05	1.1
Value (Grading)	1	3	5	7	9
1. Material		Un-reinforced	Reinforced		
2. Seam Attachment systems	Solvent based adhesive	Pressure sensitive Tapes/mechanically fasteners	Heat Weld		
3. Weak-points: numbers of penetrations	> 28	23-27	18-22	13-17	< 13

5.2.2 Factor Class B: Design Level

Description:

This factor reflects the component's installation and is typically based on the level of shelter and protection for agents provided by the design of the building.

Interpretation:

The emphasis of this factor is on design details for system protections. In the roof context, this may mean adding gravel as protection to a roof surface. In this study, the majority of buildings' roof design and specifications come from the same source (using roof prototype), and only subtle deviation details are found. Therefore, this factor is considered equal in all observed cases, and is not included in the analysis.

5.2.3 Factor Class C: Work Execution Level

Description:

This factor represents the level of skill and control in the site work. It is based on whether the site work is in accordance with manufacturers' recommendations and is tightly controlled, including issues such as storage, protection during installation, and the number of trades required for each activity.

Interpretation:

This factor emphasizes worksite management and quality control during roof installation. However, from the interviews, site supervision is seldom performed. For the studied roofs, the roof installers are directly hired from the building owner and the crews are generally certified by the manufacturers. According to the owner's construction specifications, roof structure and site preparation are mandated before the roof installation begins. This requirement enhances a consistency of work conditions. A new measurement is proposed to represent this factor.

The roof call-back frequencies are used to represent the quality of work execution. During the interviews, at least one-third of roof experts agree that roof leaks in the first few years are a result of workmanship problems. The call-back frequencies are also used in Chew et al. (2003). In this study, the average of all reported roof problems per month, within the first year, is used as a gauge of work execution quality. The smaller the numbers of call-backs, the better the quality of work execution. In this sample, the standard deviation is approximately 0.14. The minimum value is 0.00 and the maximum is 0.75. Table 5.2 shows the condition level of each sub-factor in this factor class.

Table 5.2 Variables Represented Factor Class C

Value (ISO)	**0.9**	**0.95**	**1.0**	**1.05**	**1.1**
Value (Grading)	**1**	**3**	**5**	**7**	**9**
Workmanship: Average roof leaks and repairs per month within the first year	0.60-0.75	0.45-0.59	0.29-0.44	0.15-0.29	0-0.14

5.2.4 Factor Class D: Indoor Environment

Description:

This factor includes the indoor environment, such as exposure to and severity of indoor agents that cause degradation. The general use of the building is taken into account together with relevant local aspects, such as locations subject to wetting.

Interpretation:

The emphasis of this factor is agents or activities inside the structure that may jeopardize the study system. The study stores are owned by a single entity for the same purpose of serving as a warehouse-retailer. The stores have similar configurations, interior setting-temperature, pressure, lay-out and building systems used for commercial benefits. Therefore, this factor is considered equal in all observed cases, and is not included in the analysis.

5.2.5 Factor Class E: Outdoor Environment

Description:

This factor includes the outdoor environment, such as the exposure to and severity of outdoor agents that cause degradation. A meso or local-level designation may be adequate for this factor class. Factor Class E is quantified in terms of degradation agent intensities**.**

Interpretation:

External agents that may degrade the roof systems are the emphasis of this factor class. The major external environment degradation factors of roofs are temperature, solar radiation, precipitation and ozone (Bailey, Cash et al. 2002). In this study, all but ozone are used, due to the availability of the information.

Cash (2003) claims that temperature can be used as a prime indicator of the local climate. Air temperature is considered a result of changes in solar radiation, wind, rain, cloud cover, and other environmental influences. The higher the average air temperature at the location, the shorter the membrane service life (Cash 2003). Based on the interpretation, the followings variables are used to represent this factor class.

1. Average normal temperature-30 year:

Table 5.3 Mean Years of Durability at Various Thermal Loadings (Cash 2003)

Membrane Type	Thermal Load, K (F)			
	280 (44.3)	290 (62.3)	300 (80.3)	310 (98.3)
EPDM	20.1	15.4	12.0	9.5
Thermoplastic Polyolifin (TPO)	14.0	12.8	11.8	10.2

As shown in Table 5.3, roofs located where the average temperature is approximately 44.3 F (280 K) have the longest years of durability. While the higher average temperature reduces the roof durability (Cash 2003), there is not evidence of the longevity for roofs located where temperature is below 44.3 F. Based on the trend, the study assumes that roofs located in colder areas have a higher durability. Average air temperatures collected by the National Climatic Data Center (NCDC) for the last 30 years are used in this sub-factor.

2. Precipitation: Average precipitation (snow, rain, and others) collected by the National Climatic Data Center (NCDC) for the past 30 years are used. In this context, the less the amount of precipitation, the fewer problems the roof will experience.

3. Solar radiation: Average 30 year solar radiation collected by the Renewable Resource Data Center (RReDC), the National Renewable Energy Laboratory is used. In this context, the lesser the amount of solar radiation, the better chance the roof will survive.

Although there was no conclusive evidence of impact on roof longevity from the expert interviews, the following factors are also included in the analysis as additional variables for Factor Class E.

4. Average temperature fluctuations: From interviews, roof expansion or contraction are among the many root causes of roof problems. The smaller range of air temperature changes during a day is assumed to cause less movement and, therefore, fewer problems found in materials and roof assemblies.

5. *Wind zone*: Wind zone is one of many criteria used for roof design; therefore, it is worth examining. Store roofs located in a lower wind speed zone are assumed to have fewer roof problems.

6. *Environment- micro settings:* Micro settings around buildings are also among the criteria used for roof design that directly influence wind-speed and directions (Patterson and Mehta 2001). A good combination of open space and obstacle is assumed to be better. According to the level presented in HMDA, a good combination is defined as stores surrounded by approximately 30-70% of either open space or obstacles (woods or structures). The description of each category used in this factor class is described in Chapter 3. Table 5.4 presents the condition level of each sub-factor in this factor class.

Table 5.4 Variables Represented Factor Class E

Value (ISO)	**0.9**	**0.95**	**1.0**	**1.05**	**1.1**
Value (Grading)	**1**	**3**	**5**	**7**	**9**
Temperature (1,2)	> 71.61	62.61 to 71.60	53.61 to 62.60	44.61 to 53.60	< 44.60
Precipitation (1,2)	> 83.19	64.46 to 83.18	45.76 to 64.45	27.00 to 45.75	< 26.99
Solar Radiation (1,2)	> 5190	4647 to 5189	4103 to 4646	3560 to 4102	< 3559
Average temperature fluctuations (2)	> 28.83	24.05 to 28.82	19.27 to 24.04	14.49 to 19.26	< 14.48
Wind Zone (2)	> 160	140-150	120-130	100-110	85 -90
Micro Environment (2)	1,4	3	2		

Note: (1) represents the original sub-factors for this factor class
(2) represents the additional interest sub-factor to test the factor class

5.2.6 Factor Class F: Usage Condition

Description:

This factor reflects the impact of use on the building asset. The specific use of the space where the component is installed or the assembly constructed is likely to be relevant; external locations may also be pertinent.

Interpretation:

This factor emphasizes activities or the usage of space that directly affect the studied component's service life. For roofs, generally only limited staff is permitted access to the roofs. In this study, only roofers and HVAC staff are allowed to be on roofs. The average traffic frequencies generated by these groups of staff are used to represent this factor class.

1. *Average per month frequencies of HVAC staff on roofs:* The frequencies of HVAC staff performing either maintenance, filter changing or repair on roofs, are tabulated and recorded to represent this factor.

2. *Average per month frequencies of roofers access roofs:* Using the same dataset source, the frequencies of roofers on roofs are calculated. All activities on roofs, including roof repair or cleaning, are captured.

For both variables, less traffic on roofs is better for roof longevity. Table 5.5 shows the condition levels of each sub-factor in this factor class.

Table 5.5 Variables Represented Factor Class F

Value (ISO)	**0.9**	**0.95**	**1.0**	**1.05**	**1.1**
Value (Grading)	**1**	**3**	**5**	**7**	**9**
Roofer Traffic	> 0.301	0.226 to 0.300	0.151 to 0.225	0.076 to 0.150	< 0.075
HVAC Staff Traffic	> 1.75	1.31 to 1.74	0.88 to 1.30	0.44 to 0.87	< 0.43

5.2.7 Factor Class G: Maintenance Level

Description:

This factor includes the level of maintenance assumed. For certain components that are inaccessible or require special equipment for access, a particularly low maintenance level should be considered. The expertise of cleaning and the risk of the introduction of agents not normally found can also be taken into account.

Interpretation:

The emphasis of this factor is on the frequency of roof maintenance. It also included whether or not the study area has maintenance plans in place. For the study roofs, there are no maintenance plans in place. Roof maintenance typically is reactive; only when problems arise can the repair request be generated and problems are corrected. However, from time to time, there are requests to have gutters and roofs cleaned due to anticipated heavy storms. Therefore, the roof inspection and cleaning frequencies are extracted from the maintenance records and are tabulated to represent this factor class. Higher frequencies of roof maintenance are preferred. Table 5.6 displays the condition levels of the representative variables in this factor class.

Table 5.6 Variables Represented Factor Class G

Value (ISO)	**0.9**	**0.95**	**1.0**	**1.05**	**1.1**
Value (Grading)	**1**	**3**	**5**	**7**	**9**
Average Roof Inspection per month	<0.05	0.06-0.10	0.11-0.15	0.16-0.20	> 0.21

5.3 Relationship Analyses and Results

The data is then entered into Equation 2.1 to estimate the service of each roof case. The reference service life (RSL) is assumed to be equal in all cases (same roof types) and is substituted with a real number when the actual data of reference service life is available. The ESL values, however, depends on how each factor method is derived, and the value can be seen in Appendix I. The ESL and first-time roof leaks data are then inputted into the SPSS 13 under Pearson correlation analysis. Figure 5.1 presents Trial 1-56 relationship analysis results.

Trial 1

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 1	x		x					x			

Result

Trial 1Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.080
	Sig. (2-tailed)		.162
	N	310	310
ESL	Pearson Correlation	.080	1
	Sig. (2-tailed)	.162	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Trial 2

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 2		x	x					x			

Result

Trial 2 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.048
	Sig. (2-tailed)		.399
	N	310	310
ESL	Pearson Correlation	.048	1
	Sig. (2-tailed)	.399	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Figure 5.1 Trial 1-56 Relationship Analysis Results

Trial 3

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 3	x			x				x			

Result

Trial 3 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.071
	Sig. (2-tailed)		.214
	N	310	310
ESL	Pearson Correlation	.071	1
	Sig. (2-tailed)	.214	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Trial 4

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 4	x			x			x	x			

Result

Trial 4 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.107
	Sig. (2-tailed)		.059
	N	310	310
ESL	Pearson Correlation	.107	1
	Sig. (2-tailed)	.059	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Figure 5.1 (Continued)

Trial 5

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 5		x		x				x			

Result

Trial 5 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.033
	Sig. (2-tailed)		.565
	N	310	310
ESL	Pearson Correlation	.033	1
	Sig. (2-tailed)	.565	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Trial 6

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 6		x		x			x	x			

Result

Trial 6 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.110
	Sig. (2-tailed)		.052
	N	310	310
ESL	Pearson Correlation	.110	1
	Sig. (2-tailed)	.052	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Figure 5.1 (Continued)

Trial 7

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 7	x				x			x			

Result

Trial 7 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.045
	Sig. (2-tailed)		.426
	N	310	310
ESL	Pearson Correlation	.045	1
	Sig. (2-tailed)	.426	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Trial 8

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 8	x				x		x	x			

Result

Trial 8 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.027
	Sig. (2-tailed)		.640
	N	310	310
ESL	Pearson Correlation	.027	1
	Sig. (2-tailed)	.640	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Figure 5.1 (Continued)

Trial 9

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 9		x			x			x			

Result

Trial 9 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.029
	Sig. (2-tailed)		.611
	N	310	310
ESL	Pearson Correlation	.029	1
	Sig. (2-tailed)	.611	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Trial 10

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 10		x			x		x	x			

Result

Trial 10 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.035
	Sig. (2-tailed)		.538
	N	310	310
ESL	Pearson Correlation	.035	1
	Sig. (2-tailed)	.538	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Figure 5.1 (Continued)

Trial 11

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 11	x					x		x			

Result

Trial 11 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.045
	Sig. (2-tailed)		.426
	N	310	310
ESL	Pearson Correlation	.045	1
	Sig. (2-tailed)	.426	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Trial 12

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 12	x					x	x	x			

Result

Trial 12 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.027
	Sig. (2-tailed)		.640
	N	310	310
ESL	Pearson Correlation	.027	1
	Sig. (2-tailed)	.640	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Figure 5.1 (Continued)

Trial 13

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 13		x				x		x			

Result

Trial 13 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.029
	Sig. (2-tailed)		.611
	N	310	310
ESL	Pearson Correlation	.029	1
	Sig. (2-tailed)	.611	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Trial 14

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 14		x				x	x	x			

Result

Trial 14 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.035
	Sig. (2-tailed)		.538
	N	310	310
ESL	Pearson Correlation	.035	1
	Sig. (2-tailed)	.538	
	N	310	310

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Figure 5.1 (Continued)

Trial 15

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 15	x		x						x		

Result

Trial 15 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.092
	Sig. (2-tailed)		.188
	N	205	205
FESL	Pearson Correlation	.092	1
	Sig. (2-tailed)	.188	
	N	205	205

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Trial 16

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 16		x	x						x		

Result

Trial 16 Correlation Result

		LEAK	IESL
LEAK	Pearson Correlation	1	.188(**)
	Sig. (2-tailed)		.007
	N	205	205
IESL	Pearson Correlation	.188(**)	1
	Sig. (2-tailed)	.007	
	N	205	205

** Correlation is significant at the 0.01 level (2-tailed).

There is **a small positive significant relationship** between the estimated service life (ESL) and the first-time roof leak (month), r = .19, p < .01.

Figure 5.1 (Continued)

Trial 17

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 17	x			x					x		

Result

Trial 17 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.108
	Sig. (2-tailed)		.122
	N	205	205
ESL	Pearson Correlation	.108	1
	Sig. (2-tailed)	.122	
	N	205	205

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak (month).

Trial 18

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 18	x			x			x		x		

Result

Trial 18 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.144(*)
	Sig. (2-tailed)		.040
	N	205	205
ESL	Pearson Correlation	.144(*)	1
	Sig. (2-tailed)	.040	
	N	205	205

* Correlation is significant at the 0.05 level (2-tailed).

There is **a small positive significant relationship** between the estimated service life (ESL) and the first-time roof leak (month), r = .15, $p < .05$.

Figure 5.1 (Continued)

Trial 19

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases		
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 19		x		x					x		

Result

Trial 19 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.209(**)
	Sig. (2-tailed)		.003
	N	205	205
ESL	Pearson Correlation	.209(**)	1
	Sig. (2-tailed)	.003	
	N	205	205

** Correlation is significant at the 0.01 level (2-tailed).

There is **a small positive significant relationship** between the estimated service life (ESL) and the first-time roof leak (month), $r = .21$, $p < 0.01$.

Trial 20

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases		
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 20		x		x			x		x		

Result

Trial 20 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.237(**)
	Sig. (2-tailed)		.001
	N	205	205
ESL	Pearson Correlation	.237(**)	1
	Sig. (2-tailed)	.001	
	N	205	205

** Correlation is significant at the 0.01 level (2-tailed).

There is **a small positive significant relationship** between the estimated service life (ESL) and the first-time roof leak (month), $r = .24$, $p < .01$.

Figure 5.1 (Continued)

Trial 21

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 21	x				x				x		

Result

Trial 21 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.147(*)
	Sig. (2-tailed)		.035
	N	205	205
ESL	Pearson Correlation	.147(*)	1
	Sig. (2-tailed)	.035	
	N	205	205

* Correlation is significant at the 0.05 level (2-tailed).

There is **a small positive significant relationship** between the estimated service life (ESL) and the first-time roof leak (month), r = .15, $p < .05$.

Trial 22

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 22	X				x		x		x		

Result

Trial 22 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.151(*)
	Sig. (2-tailed)		.031
	N	205	205
ESL	Pearson Correlation	.151(*)	1
	Sig. (2-tailed)	.031	
	N	205	205

* Correlation is significant at the 0.05 level (2-tailed).

There is **a small positive significant relationship** between the estimated service life (ESL) and the first-time roof leak (month), r = .15, $p < .05$.

Figure 5.1 (Continued)

Trial 23

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 23		x			x				x		

Result

Trial 23 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.315(**)
	Sig. (2-tailed)		.000
	N	205	205
ESL	Pearson Correlation	.315(**)	1
	Sig. (2-tailed)	.000	
	N	205	205

** Correlation is significant at the 0.01 level (2-tailed).

There is **a medium positive significant relationship** between the estimated service life (ESL) and the first-time roof leak (month), r = .32, $p < .01$.

Trial 24

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 24		x			x		x		x		

Result

Trial 24 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.339(**)
	Sig. (2-tailed)		.000
	N	205	205
ESL	Pearson Correlation	.339(**)	1
	Sig. (2-tailed)	.000	
	N	205	205

** Correlation is significant at the 0.01 level (2-tailed).

There is **a medium positive significant relationship** between the estimated service life (ESL) and the first-time roof leak (month), r = .34, $p < .01$.

Figure 5.1 (Continued)

Trial 25

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 25	X					x			x		

Result

Trial 25 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.147(*)
	Sig. (2-tailed)		.035
	N	205	205
ESL	Pearson Correlation	.147(*)	1
	Sig. (2-tailed)	.035	
	N	205	205

* Correlation is significant at the 0.05 level (2-tailed).

There is **a small positive significant relationship** between the estimated service life (ESL) and the first-time roof leak (month), r = .15, *p* <.05.

Trial 26

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 26	X					x	x		x		

Result

Trial 26 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.151(*)
	Sig. (2-tailed)		.031
	N	205	205
ESL	Pearson Correlation	.151(*)	1
	Sig. (2-tailed)	.031	
	N	205	205

* Correlation is significant at the 0.05 level (2-tailed).

There is **a small positive significant relationship** between the estimated service life (ESL) using factor classes and the first-time roof leak (month), r = .15, *p* < .05.

Figure 5.1 (Continued)

Trial 27

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 27		x				x			x		

Result

Trial 27 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.315(**)
	Sig. (2-tailed)		.000
	N	205	205
ESL	Pearson Correlation	.315(**)	1
	Sig. (2-tailed)	.000	
	N	205	205

** Correlation is significant at the 0.01 level (2-tailed).

There is **a medium positive significant relationship** between the estimated service life (ESL) and the first-time roof leak (month), r = .32, $p < .01$.

Trial 28

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 28		x				x	x		x		

Result

Trial 28 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.339(**)
	Sig. (2-tailed)		.000
	N	205	205
ESL	Pearson Correlation	.339(**)	1
	Sig. (2-tailed)	.000	
	N	205	205

** Correlation is significant at the 0.01 level (2-tailed).

There is **a medium positive significant relationship** between the estimated service life (ESL) and the first-time roof leak (month), r = .34, $p < 0.01$.

Figure 5.1 (Continued)

Trial 29

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 29	x		x							x	

Result

Trial 29 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.227
	Sig. (2-tailed)		.116
	N	49	49
ESL	Pearson Correlation	.227	1
	Sig. (2-tailed)	.116	
	N	49	49

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- group leaks (month), r = .08, *p* = .12.

Trial 30

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 30	x		x								x

Result

Trial 30 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	-.001
	Sig. (2-tailed)		.989
	N	156	156
ESL	Pearson Correlation	-.001	1
	Sig. (2-tailed)	.989	
	N	156	156

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- spotted (month).

Figure 5.1 (Continued)

Trial 31

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 31		x	x							x	

Result

Trial 31 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.255
	Sig. (2-tailed)		.076
	N	49	49
ESL	Pearson Correlation	.255	1
	Sig. (2-tailed)	.076	
	N	49	49

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak-grouped (month).

Trial 32

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 32		x	x								x

Result

Trial 32 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.155
	Sig. (2-tailed)		.054
	N	156	156
ESL	Pearson Correlation	.155	1
	Sig. (2-tailed)	.054	
	N	156	156

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak-spotted (month).

Figure 5.1 (Continued)

Trial 33

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 33	x			x						x	

Result

Trial 33 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.163
	Sig. (2-tailed)		.262
	N	49	49
ESL	Pearson Correlation	.163	1
	Sig. (2-tailed)	.262	
	N	49	49

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- grouped (month).

Trial 34

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 34	x			x							x

Result

Trial 34 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.058
	Sig. (2-tailed)		.474
	N	156	156
ESL	Pearson Correlation	.058	1
	Sig. (2-tailed)	.474	
	N	156	156

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- spotted (month).

Figure 5.1 (Continued)

Trial 35

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 35	x			x			x			x	

Result

Trial 35 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.141
	Sig. (2-tailed)		.334
	N	49	49
ESL	Pearson Correlation	.141	1
	Sig. (2-tailed)	.334	
	N	49	49

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- grouped (month).

Trial 36

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 36	x			x			x				x

Result

Trial 36 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.142
	Sig. (2-tailed)		.077
	N	156	156
ESL	Pearson Correlation	.142	1
	Sig. (2-tailed)	.077	
	N	156	156

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- spotted (month).

Figure 5.1 (Continued)

Trial 37

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 37		x		x						x	

Result

Trial 37 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.231
	Sig. (2-tailed)		.110
	N	49	49
ESL	Pearson Correlation	.231	1
	Sig. (2-tailed)	.110	
	N	49	49

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- grouped (month).

Trial 38

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 38		x		x							x

Result

Trial 38 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.199(*)
	Sig. (2-tailed)		.013
	N	156	156
ESL	Pearson Correlation	.199(*)	1
	Sig. (2-tailed)	.013	
	N	156	156

* Correlation is significant at the 0.05 level (2-tailed).

There is **a small positive significant relationship** between the estimated service life (ESL) and the first-time roof leak- spotted (month), $r = .20$, $p < .05$.

Figure 5.1 (Continued)

Trial 39

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 39		x		x			x			x	

Result

Trial 39 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.181
	Sig. (2-tailed)		.214
	N	49	49
ESL	Pearson Correlation	.181	1
	Sig. (2-tailed)	.214	
	N	49	49

There is **<u>no significant relationship</u>** between the estimated service life (ESL) and the first-time roof leak- grouped (month).

Trial 40

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 40		x		x			x				x

Result

Trial 40 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.269(**)
	Sig. (2-tailed)		.001
	N	156	156
ESL	Pearson Correlation	.269(**)	1
	Sig. (2-tailed)	.001	
	N	156	156

** Correlation is significant at the 0.01 level (2-tailed).

There is **<u>a small positive significant relationship</u>** between the estimated service life (ESL) and the first-time roof leak- spotted (month), r = .27, $p < .01$.

Figure 5.1 (Continued)

Trial 41

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 41	x				X					x	

Result

Trial 41 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.268
	Sig. (2-tailed)		.062
	N	49	49
ESL	Pearson Correlation	.268	1
	Sig. (2-tailed)	.062	
	N	49	49

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak-grouped (month).

Trial 42

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 42	x				X						x

Result

Trial 42 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.062
	Sig. (2-tailed)		.445
	N	156	156
ESL	Pearson Correlation	.062	1
	Sig. (2-tailed)	.445	
	N	156	156

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak-spotted (month).

Figure 5.1 (Continued)

Trial 43

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 43	x				X		x			x	

Result

Trial 43 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.268
	Sig. (2-tailed)		.063
	N	49	49
ESL	Pearson Correlation	.268	1
	Sig. (2-tailed)	.063	
	N	49	49

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- grouped (month).

Trial 44

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 44	x				x		x				x

Result

Trial 44 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.073
	Sig. (2-tailed)		.366
	N	156	156
ESL	Pearson Correlation	.073	1
	Sig. (2-tailed)	.366	
	N	156	156

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- spotted (month).

Figure 5.1 (Continued)

Trial 45

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 45		x			x					x	

Result

Trial 45 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.352(*)
	Sig. (2-tailed)		.013
	N	49	49
ESL	Pearson Correlation	.352(*)	1
	Sig. (2-tailed)	.013	
	N	49	49

* Correlation is significant at the 0.05 level (2-tailed).

There is **a medium positive significant relationship** between the estimated service life (ESL) and the first-time roof leak- grouped (month), r = .35, $p < .05$.

Trial 46

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 46		x			x						x

Result

Trial 46 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.296(**)
	Sig. (2-tailed)		.000
	N	156	156
ESL	Pearson Correlation	.296(**)	1
	Sig. (2-tailed)	.000	
	N	156	156

** Correlation is significant at the 0.01 level (2-tailed).

There is **a medium positive significant relationship** between the estimated service life (ESL) and the first-time roof leak- spotted (month), r = .30, $p < .001$.

Figure 5.1 (Continued)

Trial 47

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 47		x			x		x			x	

Result

Trial 47 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.355(*)
	Sig. (2-tailed)		.012
	N	49	49
ESL	Pearson Correlation	.355(*)	1
	Sig. (2-tailed)	.012	
	N	49	49

* Correlation is significant at the 0.05 level (2-tailed).

There is **a medium positive significant relationship** between the estimated service life (ESL) and the first-time roof leak- grouped (month), r = .36, $p < .05$.

Trial 48

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 48		x			x		x				x

Result

Trial 48 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.334(**)
	Sig. (2-tailed)		.000
	N	156	156
ESL	Pearson Correlation	.334(**)	1
	Sig. (2-tailed)	.000	
	N	156	156

** Correlation is significant at the 0.01 level (2-tailed).

There is **a medium positive significant relationship** between the estimated service life (ESL) and the first-time roof leak- spotted (month), r = .33, $p < .001$.

Figure 5.1 (Continued)

Trial 49

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 49	x					x				x	

Result

Trial 49 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.268
	Sig. (2-tailed)		.062
	N	49	49
ESL	Pearson Correlation	.268	1
	Sig. (2-tailed)	.062	
	N	49	49

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- grouped (month).

Trial 50

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 50	x					x					x

Result

Trial 50 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.062
	Sig. (2-tailed)		.445
	N	156	156
ESL	Pearson Correlation	.062	1
	Sig. (2-tailed)	.445	
	N	156	156

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- spotted (month).

Figure 5.1 (Continued)

Trial 51

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 51	x					x	x			x	

Result

Trial 51 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.268
	Sig. (2-tailed)		.063
	N	49	49
ESL	Pearson Correlation	.268	1
	Sig. (2-tailed)	.063	
	N	49	49

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- grouped (month).

Trial 52

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 52	x					x	x				x

Result

Trial 52 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.073
	Sig. (2-tailed)		.366
	N	156	156
ESL	Pearson Correlation	.073	1
	Sig. (2-tailed)	.366	
	N	156	156

There is **no significant relationship** between the estimated service life (ESL) and the first-time roof leak- spotted (month).

Figure 5.1 (Continued)

Trial 53

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 53		x				x				x	

Result

Trial 53 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.352(*)
	Sig. (2-tailed)		.013
	N	49	49
ESL	Pearson Correlation	.352(*)	1
	Sig. (2-tailed)	.013	
	N	49	49

* Correlation is significant at the 0.05 level (2-tailed).

There is **a medium positive significant relationship** between the estimated service life (ESL) and the first-time roof leak- grouped (month), r = .35, $p < .05$.

Trial 54

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 54		x				x					x

Result

Trial 54 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.296(**)
	Sig. (2-tailed)		.000
	N	156	156
ESL	Pearson Correlation	.296(**)	1
	Sig. (2-tailed)	.000	
	N	156	156

** Correlation is significant at the 0.01 level (2-tailed).

There is **a medium positive significant relationship** between the estimated service life (ESL) and the first-time roof leak- spotted (month), r = .30, $p < .001$.

Figure 5.1 (Continued)

Trial 55

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 55		x				x	x			x	

Result

Trial 55 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.355(*)
	Sig. (2-tailed)		.012
	N	49	49
ESL	Pearson Correlation	.355(*)	1
	Sig. (2-tailed)	.012	
	N	49	49

* Correlation is significant at the 0.05 level (2-tailed).

There is **a medium positive significant relationship** between the estimated service life (ESL) and the first-time roof leak- grouped (month), r = .36, p < .05.

Trial 56

Condition

Trial	Coding System		Derived Factor Classes				Add. Factors	Observed Cases			
								All	Only Leaks	Selected Leak Cases	
	Grading	ISO	Single	Multiply	Average	Add				Group	spotted
Trial 56		x				x	x				x

Result

Trial 56 Correlation Result

		LEAK	ESL
LEAK	Pearson Correlation	1	.334(**)
	Sig. (2-tailed)		.000
	N	156	156
ESL	Pearson Correlation	.334(**)	1
	Sig. (2-tailed)	.000	
	N	156	156

** Correlation is significant at the 0.01 level (2-tailed).

There is **a medium positive significant relationship** between the estimated service life (ESL) and the first-time roof leak- spotted (month), r = .33, p < .001.

Figure 5.1 (Continued)

5.4 Summary

The 56 analysis trials prove that there are some significant correlations between the ESL of roofs assemblies using 'Factor Method' and first-time roof leaks. The strengths of significant correlations vary from low-to-medium (1.44 – 3.39) with significant < .05 or .001. Nevertheless, to be able to detect the significant, a certain set of conditions need to be satisfied. Further explanation, analysis and interpretation from RSLP are explained in the following chapter.

CHAPTER 6

RESULTS DISCUSSION, CONCLUSION, AND RECOMMENDATIONS FOR FUTURE RESEARCH

6.1 Purpose

This chapter describes and interprets the final model from HMDA, as well as the relationship between the estimated service life and first-time leak results from RSLP. Research conclusions, contributions and potential extended research studies are presented in the last part of the chapter.

6.2 HMDA Research Results

The model development begins by simultaneously fitting three potential variables (Roof Age (AG), Workmanship Quality (WE), and average Roof Repair (RR)) from Trial 4 in SPSS logistic regression analysis. A total of 303 observed roofs are included in this process; missing values are not an issue for this data. Roof leaks are coded as '1' and '0' for roofs that do not report a leak within the first three years of their installation. The results and interpretation of the final model are presented in this section.

6.2.1 Block 0 Results

The initial model, Block 0, is derived by fitting only the constant in the regression equation. The -2 log-likelihood, which represents how well the model fits, is 384.326. Without any prior knowledge, the SPSS predicts that every roof 'leaks'; this prediction is 67 % correct. The coefficients for the variables not in the model show a significant difference from zero, χ^2 (3) = 173.56, $p < .001$. This means that adding one or more of the variables to the model will significantly affect the predictive power and the Block 0 model should be rejected. The results of Block 0 model are shown in Table 6.1.

Table 6.1 Final Model Block 0 Variables Not in the Equation

Variables	Score	df	Sig.
ZAG	94.675	1	.000
ZWE	74.101	1	.000
ZRR	12.130	1	.000
Overall Statistics	173.556	3	.000

6.2.2 Block 1 Results

In this step, all variables (AG, WE, RR) are included in the model. The Block 1 model improves its prediction capability over the initial model by 291.51; this value is significant at a 0.05 level. However, 92.81 of variables in the data still need to be explained. By including variables, the model has the power to correctly predict at a rate of 92.1%, compared to 67% when only the constant is included; this equates to a 37% improvement.

The Cox and Snell-R square and Negalkerke R-square also confirm that the model accounts for approximately 60-86 % of the variance in roof leaks (roughly one-fifth of what causes roof leaks is still unknown).

Model Coefficients

	Chi-square	df	Sig.
Model	291.508	3	.000

Model Summary

-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
92.818	.618	.860

Classification Table

Observed		Predicted		
		Leaks		(%) Correct
		No Leak	Leak	
Leaks	No Leak	86	14	86.0
	Leak	10	193	95.1
Overall Percentage				92.1

Variables in the Final Model

	B	S.E.	Wald	df	Sig.	Exp(B)	95.0% C.I.for EXP(B)	
							Lower	Upper
AG	3.355	.518	42.019	1	.000	28.641	10.386	78.981
WE	7.123	1.115	40.849	1	.000	1240.665	139.623	11024.362
RR	-2.388	.467	26.181	1	.000	.092	.037	.229
Constant	3.647	.606	36.205	1	.000	38.365		

Correlations between each Variable and Leaks

		AG	WE	RR	Leaks
AG	Pearson Correlation	1	.005	-.021	**.517(**)**
	Sig. (2-tailed)		.936	.713	.000
	N	311	311	311	311
WE	Pearson Correlation	.005	1	.647(**)	**.470(**)**
	Sig. (2-tailed)	.936		.000	.000
	N	311	311	311	311
RR	Pearson Correlation	-.021	.647(**)	1	**.165(**)**
	Sig. (2-tailed)	.713	.000		.003
	N	311	311	311	311
Leaks	Pearson Correlation	.517(**)	.470(**)	.165(**)	1
	Sig. (2-tailed)	.000	.000	.003	
	N	311	311	311	311

** Correlation is significant at the 0.01 level (2-tailed)

Figure 6.1 Final Model Results

Figure 6.1 shows that Roof Age (AG), Workmanship Quality (WE), and average Roof Repair (RR) have logit coefficients significantly different from zero (Wald statistic *S*ig < 0.001). The correlation table also confirms the significant correlation of these variables to roof leaks (small and medium relationship with $p < 0.001$, 0.01). It is safe to conclude that these three variables make a significant contribution to the prediction of roof leaks.

6.2.3 Outlier Testing

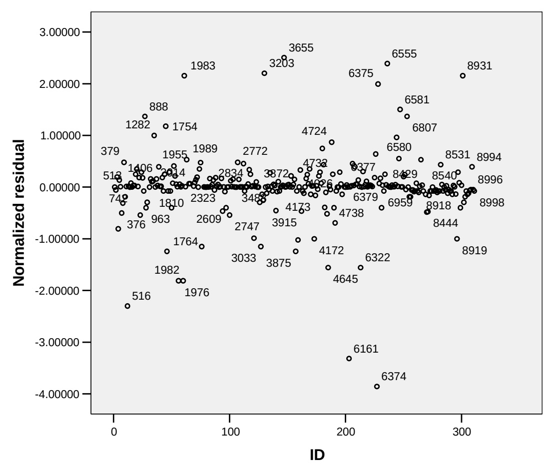

Figure 6.2 Final Model Outliner (Normalized Residual)

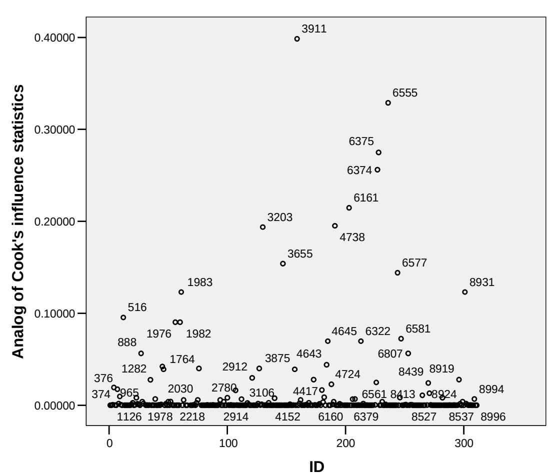

Figure 6.3 Final Model Outliner (Cook's Influence Statistics)

As shown in Figure 6.2 and 6.3, both residual graphs show normal distributed residuals; no irregular patterns are found. Nevertheless, a couple of potential outlier cases are detected in the normalized residual graph (Figure 6.2); no influence case in this model can be identified (COO < 1). It is safe to assume there are no severe outliers in the model.

6.2.4 Variable Interpretation: Variable Relations with Roof Leaks

Two out of the three variables in the model have a positive relationship with leak problems: Roof Age (Age) and Workmanship (WE). An increase in one unit of these variables increases the odds of roof leaks. In this case, the increasing powers are equal to the variables' odds ratios. The average Roof Repair (RR), on the other hand, has a negative relationship with roof leaks. An increase of the average frequency of roof repair decreases the odds of leaks. A detailed explanation of the relationship between each variable and leak is presented in the following section.

6.2.4.1 Age (Wald statistic = 42.02, $p < .001$)

The odds (see Appendix E) of roof leaks increase by a multiplicative factor of 28, as the age of roofs increases by one month. In another words, each additional month increases the odds of leaks about 28 folds, controlling for other variables in the model. To explain in probability terms, assuming all other variables hold constant and the 5-month-old roof has 15% probability of roof leaks, a one month increase (6 month old roof) will increase the probability of roof leaks to 83%. Therefore, an increase of 1 month in roof age increases the chance of leak by 68% (see explanation in Appendix E- calculation sample). The 95% confidence interval for the odds ratio ranges from 10 to 79; based on this, we can be fairly confident that the odds of one month older roofs compared to the younger roofs in the population lie somewhere between these two values. Also, the relationship of age and roof leaks in this sample is true for the entire population of this particular retail stores (both values are above 1), when all other factors are equal.

6.2.4.2 Workmanship (Wald statistic = 40.85, $p < .001$)

The odds ratios of workmanship indicates that if the average per month of roof recalls within the first year increases by one, the odds of roof leak incidences increases tremendously (more than 100 times), when other variables are controlled. The 95% confidence interval also has a wide range, from 139 to more than 1000 times, for the sample stores. Even though the 95% confidence interval of the change in one unit is extremely wide, we can still be very confident that the value of odds ratio in the population lies somewhere between these two values. The relationship of workmanship and leaks is also true for the entire similar structure roofs (the value does not cross 1), when other variables are equal.

6.2.4.3 Roof Repair (RR) (Wald statistic = 26.18, $p < .001$)

The odds ratios of roof repair indicates that if the average roof repair per month increases by one, the odds of leak incidences will decrease. Put another way, with all other factors held equal, an increase of an average of one roof repair per month decreases the odds of roof leaks by 91%. The decreased odds are between 77-96%, which is relatively narrow. We can be very confident that the value of change of odds in the population lies somewhere between these two values. The relationship of roof repairs and roof leaks found in this sample is true for the entire population of this particular retail stores (both values are above 1), when all other factors are equal.

6.3 RSLP Results

Fifty-six analysis trials are performed to investigate the relationship between estimated service life (ESL) of roof assemblies and the age of the first-time leak. In this process, the ESL is calculated using different combinations of value coding, observed cases, and means to derive factor classes based on 'Factor Method' principles. The first-time leak is extracted from maintenance records.

The factor classes derived from the average and add yield the same results in all conditions; therefore only the single, average, and multiply sub-factor results are presented. Trials 11-14, 25-28, and 49-56 are, therefore, omitted. The following table presents the correlation result of each trial.

Table 6.2 Correlation between Estimated Service Life and First-Time Leak Results

Trials	Pearson	
	correlation coefficiency	significant
Trial 1	0.050	0.160
Trail 2	0.460	0.414
Trail 3	0.071	0.214
Trail 4	0.107	0.059
Trial 5	0.033	0.565
Trial 6	0.110	0.052
Trial 7	0.045	0.426
Trial 8	0.027	0.640
Trial 9	0.029	0.611
Trial 10	0.035	0.538
Trial 15	0.092	0.188
Trial 16	.188**	0.007
Trial 17	0.108	0.122
Trial 18	.144*	0.040
Trial 19	.209**	0.003
Trial 20	.237**	0.001
Trial 21	.147*	0.035
Trial 22	.151*	0.031

Table 6.2 (Continued)

Trials	Pearson	
	correlation coefficiency	significant
Trial 23	.315**	0.000
Trial 24	.339**	0.000
Trial 29	0.227	0.116
Trial 30	-0.001	0.989
Trial 31	0.255	0.076
Trial 32	0.155	0.054
Trial 33	0.163	0.262
Trial 34	0.058	0.474
Trial 35	0.141	0.334
Trial 36	0.142	0.077
Trial 37	0.231	0.110
Trial 38	.199*	0.013
Trial 39	0.181	0.214
Trial 40	.269**	0.001
Trial 41	0.268	0.062
Trial 42	0.062	0.445
Trial 43	0.268	0.063
Trial 44	0.073	0.366
Trial 45	.352*	0.013
Trial 46	.296**	0.000
Trial 47	.355*	0.012
Trial 48	.334**	0.000

When all 310 observed cases (The first attempt-TFA) are used in estimating the service life (ESL) of roofs, none of the trials (Trials 1-10) show any significant relationships with the first-time leak. However, after eliminating cases in which no leaks were observed (The second attempt-TSA), significant positive relations are detected in all but two trials (Trials 15 and 17). The results are mixed when data on roof leaks are separated and selected using specific criteria (The third attempt-TTA).

For the TTA cases, in Trials 29-48, all but one trial (Trial 30) has a positive relationship with leaks. However, only ESLs in Trials 45-48 (ISO coding and averaging sub-factors) and Trials 38 and 40 (ISO coding, multiplying sub-factors, and spotted leaks) are significantly related to the first-time leak.

For the coding system, one notification found is that all significant relationships in TTA are coded using the ISO suggested value, as significant cases in TSA. Only two trials in TSA using the grading coding system are found insignificant. The finding strongly suggests that the ISO coding values potentially yield better results and are more suitable for this dataset.

Regarding the means to derive factor classes in trials in which there were multiple sub-factors, the ESLs calculated from averaging and adding sub-factors yield the exact results; many of them reveal significant relationships of ESL and the first-time leak. The ESL values derived from a single sub-factor, or from multiplying sub-factors; however, are almost always insignificant. The only exceptions are Trial 16, when a single sub-factor is used in conjunction with ISO-suggested coding in no-leak data, and in Trials 38 and 40, when methods involving the multiplication of sub-factors are used with ISO coding in spotted leak data. It can be concluded that ESLs deriving from using a single sub-factor or mathematic multiplication of sub-factors are not suitable for this method. The additional, suspicious sub-factors in Factor E, outdoor environment, also do not increase or improve the results.

Comparing the size of correlation derived from adding or averaging sub-factors, the correlation size in TSA and TTA using ISO-suggested coding are relatively similar (ranging from 3.0-3.6- medium size). However, when changes to a grading coding system, only TSA trials are found to be significant.

6.4 Research Summary

Building owners are experiencing a rise in ownership costs. One of the rapidly growing expenditures is the maintenance of the built environment (Fitch 1992; Al-Hammad and Assaf 1997). Based on a conservative estimate, facility maintenance spending amounts to hundreds of billion of dollars per year in the United States alone (Vanier 2001). In the current business culture, facility managers lack the budgets and tools to implement proper building maintenance policies which consequently lead to numerous problems, as discussed previously in Section 2.5.3.

Roof problems, especially roof leaks, not only disrupt building operations, but can also contribute to the occurrence of severe internal Indoor Air Quality (IAQ) problems and contribute to sick building syndrome (Oliver 1997; Rivin 2001; Haverinen, Vahteristo et al. 2003). Another severe consequence is litigation costs among building owners, users, and builders (Rivin 2001; Smith 2002; Silicato 2003). One of the well-accepted causes of roof leaks is the lack of roof maintenance (Lounis, Vanier et al. 1998a). The out-of-sight, out-of-mind nature of a roof's location, misjudgment regarding roof warrantees, and a lack of relevant roof maintenance information are among the reasons contributing to the current practice of adopting a reactive roof maintenance plan or no plan at all. Therefore, the objective of this study is to propose an approach that assists facility managers in obtaining the needed information to establish a proactive roof maintenance plan.

Two main methodologies are used in this research. The first approach, Historical Maintenance Data Analysis (HMDA), investigates and pinpoints the root cause of roof leaks by thoroughly collecting and analyzing roof maintenance records. HDMA tests the hypothesis that an analysis of facility maintenance records can reveal a correlation of roof leak incidence and a set of variables. Following this approach, a mathematical model has been developed to identify relationships between potential roof leak causes and leak incidences and to predict the risk of roof leaks within the first three years of roof lives.

The second approach, Roof Service Life Prediction (RSLP), investigates the applicability of the ‘Factor Method’ which is being developed for building maintenance in general. This method, proposed by the International Organization for Standard (ISO), is used to predict the service life of building components or systems by adjusting the reference service life based on in-use conditions. The use of RSLP for leak prediction assumes that the first-time leak has a linear relationship with the estimated service life of the roof.

The scope of the study is limited to the low-slope roof with a single-ply roofing system used in the continental U.S., with the exception of Alaska, Hawaii, and California. Water penetration through roofs, especially from rain and snow, is the focus of this study. Water intrusion, caused by a movement of water (mostly diffusion of mixed vapor and liquid phases) in and through roof materials, however, is not included in this study scope. This mechanism is generally known as the moisture transmission or transfer mechanism. Also, this research does not focus on or aim to use a physical principles-based degradation model to explain roof leak incidences. Rather, it employs an empirical technique using in-use data to try to explain the potential for roof leaks caused by human involvement.

6.5 Conclusions

This research demonstrates that roof maintenance records can be used to predict and identify major factors that are likely causes of roof leaks in a mathematical causal model. Roof leaks are not totally random events and can be predicted with parameters identified in this study. The use of second source data has confirmed the usefulness of the model. The results from HMDA clearly show that three parameters (Age-AG, Workmanship-WE, and Roof Repair-RR) have a significant impact on the odds of roof leaks within the first three years of a roof life. A unit change of WE and AG increases the odds of a roof leak. On the other hand, change in RR decreases the odds of a roof leak.

The one unit positive change of the average of roof call-backs, represented as workmanship quality, within the first year has a tremendous negative ramification on the odds of roof leaks, when all other variables are held constant. This finding confirms the results from expert interviews, discussed in Section 3.5.1, that the majority of early roof failures are caused due to poor workmanship.

Roof age is another important factor directly affecting leak probabilities. An increase of one additional month increases the odds of roof leaks (probability of leaks divide by probability of no leaks) by 28 times with other factors are held constant, regardless of geographical locations or local environments. The finding confirms the drastic impact that age has on roof's performance, and the need for different maintenance regimes based on age.

The increase of roof repair, on the other hand, reduces the odds of roof leaks by 91%. The reverse impact is explained by the fact that when roof repairs are requested, the roofers are not only correcting the problems, but they also generally perform a quasi-maintenance tasks that can potentially prevent future leak incidences. The finding underlies the importance of performing roof maintenance.

Out of the three most important variables (WE, AG, and RR), only two (WE and RR) can potentially be controlled by facility managers. Lack of involvement of a roofing specialist or effective quality control during roof installation, are the most likely causes for the workmanship-related issues that substantially increase the chances of roof problems. A more-rigorous quality control procedure from facility managers needs to be put in place, in order to reduce the number of roof call-backs in the first year, and more research is needed in this area.

The other human involvement is during building occupancy and maintenance. The frequency of roof repairs that can be perceived as a quasi-roof periodic maintenance, prolongs roof life by not only restoring roofs back to water tightness conditions, but also by reducing the occurrence of future roof problems that can eventually lead to leaks. As the statistical analysis in Chapter 4 suggests, an increase in roof repair frequencies (maintenance) reduces the odds of roof leaks. The notion is similar to the practice suggested by the roofing industry that roofs should be inspected at least bi-annually.

There are no surprise findings from the HMDA; however, the study findings confirm the experience-based knowledge of roof industry experts regarding root causes of roof leaks. It also sharpens understanding about the degree of significance of these three variables.

The 'Factor Method' performed in the RSLP confirms the existence of a relationship between the estimated service life (ESL) and the first-time leak. This finding proves that ESL and first-time leaks are linearly related. In this study, the correlations discovered in this proof-of-concept sample between the two parameters are positive and significant-to-highly-significant. The extent of correlation is found to be medium-to-low with a relatively normal distribution of cases. The positive correlations indicate that, with the same in-use conditions, roofs with a longer ESL will have the first-leak later than the roofs with a shorter ESL. However, only factor classes that meet the conditions described in Section 6.3 confirms this relationship. The finding also illustrates a relatively simple and useful 'Factor Method' technique in estimating the service life of roofs that can be applied to the roof maintenance decision-making process. The results from the RSLP approach nevertheless, disprove a suspicion that the data are too heterogeneous and will be difficult to detect any relationship patterns.

Another finding is that the tabulated variables, according to the ‘Factor Method’, are generally not suitable to predict the first-time leak (by mean of linear regression analysis). The R-square values are very low, ranging from 0.00-0.13. In other words, using the ESL derived from the ‘Factor Method’ technique correctly predicts only 13 percent of the first-time roof leaks. Future researchers cannot rely on this approach in predicting roof leaks, and further detailed investigation is needed.

6.6 Research Contributions

The concept of roof maintenance as an integrated part of facility management has not been adopted rigorously, even though various maintenance strategies have been proposed, as discussed in Section 2.5.4. Only the practice of bi-annual inspection is recommended by the roofing industry. Nevertheless, the practice is experience based and has not been widely adopted by many building owners; therefore, roof premature failure is still an industry problem.

This research proposes the move towards proactive maintenance that is applicable to new warehouse-type retail store roofs. The HDMA study has identified critical information, specifically the variables that most impact roof lifespan, which can be used in roof maintenance planning. The findings provide facility managers a rationale to establish a proactive roof maintenance strategy. By paying more attention toward the root causes of roof failures during roof's inception to operation, the likelihood of making mistakes that lead to leaks can be minimized.

Second, a 'Factor Method' is used to estimate the service life of roofs and a potential timeframe of a first-leak occurrence. This information provides owners with a holistic view of a required roof maintenance methodology from a building occupant's perspective.

By combining new knowledge gained from these two studies, a proactive roof maintenance management regime can be created. The estimated service life of a roof provides a reasonable estimation of a maintenance-free period. When ESL information is used in conjunction with knowledge obtained from HMDA, the new synthesis of knowledge will expand the facility maintenance professional's ability to develop and schedule a proactive roof maintenance plan. Through carefully monitoring the numbers of roof recalls in the first year, roof repairs, and the age of roofs, the initial maintenance plan, typically a bi-annual inspection, can be suitably modified to reflect actual environmental conditions and usage. A customized, on-going intervention strategy based on WE, AG and RR can develop a realistic roof leak prevention plan.

The findings from the study are valuable in providing crucial information for facility managers in establishing a proactive roof maintenance plan. In addition, the simplicity of the 'Factor Method' procedure in estimating roof life is expected to bring about the needed change in roof maintenance regimes.

6.7 Recommendations for Future Research

The research proposes a realistic and easy-to-follow data analysis methodology that feeds proactive roof maintenance management. This methodology is based on two systematic analyses of maintenance records and 'Factor Method' procedures. Preliminary findings of this study bring several issues into focus, which require follow-up investigation and are potential opportunities for expanding applications of the current study.

One of the potential follow-up items from HMDA is to investigate potential hidden causes of roof leaks in particular types of roofs and failures. In this study, the limited number of cases and high numbers of parameters prohibit the ability to separate data into smaller groups. For larger observed cases, the study can potentially identify and establish a set of criteria to separate leaks in the dataset and classify them accordingly. Different relationships and causes of roof leaks, if they exist, can possibly be detected. The results of a new study can be used to compare and confirm the findings of this research as well.

From the statistical analysis, there are about 92 variables (-2 log likelihood) in the data that still cannot be described by the logistic regression performed. This raises the question of additional data, which is needed to increase the model's ability to explain roof leaks. The types of roof-related information that need to be collected for maintenance planning purposes can potentially be a research topic for a sequential study. One major problem encountered in this study is the difficulty in acquiring data and judge the severity of potentially missing data. Currently, roof data are arbitrarily collected, at the discretion of facility managers. Some organizations solely maintain roof repair records for accounting and audit purposes. Many of them do not have maintenance plans in place and, therefore, a substantial amount of critical information is either not recorded or considered unimportant. It is difficult to establish a maintenance plan when the baseline condition of the roof is not known.

Another potential extension of current research is a study of methods to quantify the qualitative or subjective factors compiled from the roof expert interviews. In this research, the majority of potential leak-cause variables identified in the list (discussed in Section 3.5.2) are mostly installation and maintenance-related factors. There are only a few leak causes that are design-related. This is due to the fact that many design-related parameters are difficult to quantify in an objective fashion. In addition, in this study, many of design-related parameters are the same (most roofs built using the same roof prototypes). This, in fact, justifies why no design factors are included in the final analysis. A systematic method to quantify qualitative factors into meaningful quantitative inputs can potentially increase the completeness of this initial study effort.

Another potential follow-up study is to identify the optimal roof age range for a particular recommended maintenance frequency. The study can identify a cut-point maintenance frequency; for example, a specific interval for a 1- to 3-year-old roof, and a higher maintenance frequency for 3- to 6-year-old roofs.

Another important variable that can provide additional insight to roof leaks is the impact of quality control procedures in place during roof installation. There is also a need to investigate different methods to capture and represent workmanship quality in the analysis. The resulting information can reveal a more-detailed relationship of the crew quality and roof-leak incidence.

Further studies may include development of a systematic way to extrapolate the reference service life (RSL) of different in-use conditions from the currently sparsely available information from the industry. Alternatively, a systematic methodology or guidelines to quantify/identify factor classes (as described in Chapter 5) for different roof types and uses can be developed and be made publicly available. Another potential research can be to identify ways to handle factor classes with multiple sub-factors. This study shows three simple and straightforward ways to derive the factor class; however, a more-sophisticated equation can potentially yield different results. The last suggestion is to propose a method to estimate the remaining life of the existing roof assembly by adapting the 'Factor Method' principle. The integration of the information gained in the first approach can be beneficial for the new study.

Finally, as stated earlier, the amount of research on the subject of proactive roof maintenance from a whole systems approach is still very limited. In this regard, this study is a starting point for further investigation on the advantages of implementation of this process, as well as for identifying the opportunities for improvement.

APPENDIX A

Factor Class Explanations

(Excerpt from ISO 15686-8.2)

Factor Class A: Inherent performance level

Represents the grade of the component as supplied.

Factor Class B: Design Level

Reflects the component's installation in the building asset and is typically based on the level of shelter and protection for agents provided by the design of the building asset.

Factor Class C: Work Execution Level

Represents the level of skill and control in site work. It is based on whether the site work is in accordance with manufacturers' recommendations and tightly controlled, including issue such as storage, protection during installation, numbers of trades required for each activity.

Factor Class D: Indoor Environment

Includes the indoor environment, for example the exposure to indoor agents of degradation and their severity. The general use of building asset is taken into account together with relevant local aspects, for example locations subject to wetting.

Factor Class E: Outdoor Environment

Includes the outdoor environment, for example the exposure to outdoor agents of degradation and their severity. A meso- or local level designation might be adequate for this factor class.

Factor Class F: Usage Condition

Reflects the effect of use of the building asset. The specific use of the space where the component is installed or the assembly constructed is likely to be relevant. External locations might also be relevant.

Factor Class G: Maintenance Level

Includes the level of maintenance assumed. For certain components that are inaccessible or require special equipment for access, a particularly low maintenance level should be considered. The expertise of cleaning and the risk of the introduction of agents not normally found can also be taken into account.

Terms and definitions

Service Life: period of time after installation during which a building or its parts meets or exceeds the performance requirements

Reference Service Life: service life that a building or parts of a building would expect (or is predicted to have) in a certain set (reference set) of in-use conditions

Estimated Service Life: service life that a building or parts of a building would be expected to have in a set of specific in-use conditions, calculated by adjusting the reference in-use conditions in terms of materials, design, environment, use and maintenance

Design Life: Intended service life, expected service life, service life intended by the designer

Predicted Service Life: service life predicted from recorded performance over time

(Degradation) Agent: Whatever acts in a building or its parts to adversely affect its performance

Degradation Mechanism: chemical or physical path of reaction that leads to adverse changes in a critical property of a building product

Degradation: changes over time in the composition, microstructure and properties of a components or material which reduce its performance

Durability: capability of a building or its parts to perform its required function over a specified period of time under the influence of the agents anticipated in service

Failure: loss of the ability of a building of its parts to perform a specified function

Building: construction works that has the provision of shelter for its occupants or contents as one of its main purposes and is usually enclosed and designed to stand permanently in on place

(Building) Product: item manufactured or processed for incorporation in construction works

(Building) Assembly: set of components used together

(Building) Material: substance that can be used to form products or construction works

Environment: natural, man-made or induced external and internal conditions that may influence performance and use of a building and its parts

Environment Condition: state of a characteristic of the environment

Factor Method: modification of reference service life by factors to take account of the specific in use condition

APPENDIX B

Semi-Structured Questionnaires

Instructions:

This is research regarding moisture/water intrusion problems in the single-ply roof system. The research aims to identify all potential **errors, factors or any causes** (external, internal, or situational (human)) **during the design, construction, and operation that could lead to roof leaks during roof's life spans.**

This explorative interview will help the researcher collect any possible causes of roof leaks from roof experts. In order to gather all potential variables, any examples, thoughts, or suspicion based on experts work experience regarding factors causing leaks will be counted. Although this research mainly focuses on the intrusion from the exterior sources, the interior sources will also be studied, if applicable.

Questions

1. How long have you been dealing with roofs? What kinds of roofs you work with the most?

2. What kinds of roof in your opinion experience problems the most and the least, nationally and regionally?

3. Based on your experience, do single ply roofs (EPDM, PVC, TPO) experience similar problems?

4. What are typical maintenance problems (flashing, shrinkage, etc.) you have experienced and found most in single ply roofs?

5. Do most roof problems lead to roof leaks?

6. In your opinion, do these problems merely exist in Southeastern of the US or are they nation wide problems?

7. What do you think cause these problems?

8. Based on your experience, where and what are weak points of single ply roofs that could lead to leaks?

9. What do you think cause those weak points? (Design, construction, or operation errors, roof configuration, material property, weather, location)

10. Are there any certain time period of the year or patterns for roof leaks, i.e. after the first rain of the season, after long dry period?
11. Do you have any details that usually cause the problems?

12. Any other comments or thoughts regarding EPDM roof leaks.

13. What types of typical mistakes do roof designers make, if any?

14. What are typical errors causing leaks from roof installers?

15. What environmental factors (such as weather, humidity etc.) that you think could harm or cause single ply roofs to leak? And what condition would that be?

APPENDIX C

Raw Variables Collected from Expert Interviews

Table C.1Raw Variables Collected from Expert Interviews

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	Samples/reasons/activities	Total	Disagree	1	2	3	4	5	6	7	8	9
Maintenance															
	Physical damages (punctures) from human, human working on roofs	Physical damages (punctures)	Human working on roofs		9	0									
				Snow removal	**1**	**0**	**x**								
				Lack of walk pads or pipe supports with membrane underneath	**3**	**2**	**x**		**o**	**x**			**x**	**o**	
				Traffic (crushed insulations, damaged membranes)	**4**	**0**			**x**			**x**	**x**		**x**
				Other trades (HVAC, electrician) working, damaging, abusing roof flashings (w/,w/o intention); negligence left materials on roofs (screws around RTU); tools dropping	**7**	**0**	**x**	**x**	**x**	**x**	**x**		**x**		**x**
				Damage to downspouts	**1**	**0**			**x**						
				Chemical spill (HVAC) from roof equipment	**2**	**0**				**x**	**x**				
	Lack of maintenance	Deteriorated materials/ compromised roof's integrity (water tightness)	Lack of maintenance		**7**	**0**									
				Lack of proper maintenance plans (pitched pan/sealant replacement, cleaning debris, inspections, re-caulking); failing to remove old sealant before applying a new one	**6**	**0**		**x**	**x**		**x**	**x**	**x**	**x**	
				Lack of maintenance due to misunderstood warrantees	**1**	**0**						**x**			

Table C.1 (Continued)

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	Samples/reasons/activities	Total	Disagree	1	2	3	4	5	6	7	8	9
				Debris clogs/blocked	**3**	**0**			**x**					**x**	**x**
				Ponding; dissolve glue where seams/ flashings are low	**2**	**0**			**x**				**x**		
	Roof alterations cause leaks	Compromised roof's integrity (water tightness)	Human working on roofs		**4**	**0**									
				Roof alterations not put back in proper/original conditions (caulk/seals)	**2**	**0**			**x**				**x**		
				Incorrectly installing parts (maintenance parts-insulations, flashing, seams)	**2**	**0**			**x**		**x**				
				Lack of cooperation between roofers and other trades to make a proper installation or alteration of addition on roof equipment	**2**	**0**							**x**		**x**
	Facility conditions induced problems	Compromised roof's integrity (water tightness)	Human decisions		4	0									
				Pressurized buildings (too much negative sucking water in, positive blowing roof off, cracking seams)	**3**	**0**	**x**		**x**	**x**					
				Airtight buildings without proper ventilation (only exhaust fan as means to circulate air)	**1**	**0**			**x**						
				Building usage (internal activities, chemical or contamination from building uses)	**3**	**0**			**x**	**x**	**x**				

Table C.1 (Continued)

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	Samples/reasons/activities	Total	Disagree	1	2	3	4	5	6	7	8	9
Design															
	Error design/details	Compromised roof's integrity (water tightness)	Error design/details		**8**										
				Flashing details around equipment -how high flashings cover the wall(some roof systems cannot cover higher than 24 inches; if not, flashing will peel/fail)	**2**	**0**	**x**				**x**				
				Insufficient space between RTU-less than 18-inch separations between each penetration	**1**	**0**				**x**					
				Poor roof slope causing standing water-not enough positive slope, too much membrane slippage; poor drainage	**5**	**0**			**x**		**x**	**x**		**x**	**x**
				Lack of material/component movement (expand, contract) details; lack of expansion joints for long spans	**4**	**0**			**x**			**x**	**x**		**x**
				Error expansion joints details (joints interrupting the flow of drains)	**3**	**0**			**x**					**x**	**x**
				Low spots on roofs from design errors (could be from installation also)	**1**	**0**							**x**		
				Roofs too heavy from high parapets and clog drains causing collapsing roofs	**1**	**0**					**x**				
	Complex design/details	Error prone/ compromised roof's integrity (water tightness)	Complex design/details		**3**										
				Complex roofs (many penetrations, slopes, building uses, building characteristics)	**2**	**0**				**x**	**x**				
				Too many details	**1**	**0**									**x**

Table C.1 (Continued)

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	Samples/reasons/activities	Total	Disagree	1	2	3	4	5	6	7	8	9
	Designer qualifications	Error prone/ compromised roof's integrity (water tightness)	Insufficient knowledge regarding roof systems		**3**										
				Lack of roof knowledge -using wrong roof specifications (using BUR specifications for EPDM)	**1**	**0**			**x**						
				Lack of roof systems/materials details knowledge	**2**	**0**					**x**	**x**			
				Putting too much attentions in aesthetics, disregard other factors (environment)	**1**	**0**					**x**				
				Lack of long-term usage principles in roof details	**1**	**0**						**x**			
	Design Choices														
	Material/system choices	Error prone/ compromised roof's integrity (water tightness)	Insufficient knowledge/ unfamiliar with the systems		8										
				Membrane width-less seams; less risks	**3**	**0**	**x**	**x**		**x**					
				Types of materials (models/formula/reinforcement)	**3**	**0**		**x**				**x**		**x**	
				Membrane thickness	**3**	**1**	**x**			**x**		**x**		**o**	
				Wall caps choices	**1**	**0**					**x**				
				Roof finishing, face (gravels, un-ballasted-easier to detect damages)	**3**	**0**	**x**				**x**		**x**		
				Numbers of insulation layers	**3**	**0**						**x**	**x**		**x**
				Drainage systems (interior, exterior, internal gutter) and locations	**3**	**0**				**x**	**x**				**x**

Table C.1 (Continued)

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	Samples/reasons/activities	Total	Disagree	1	2	3	4	5	6	7	8	9
				Fastener types and intervals-sometimes designers do not pay attention	**3**	**1**		**x**			**x**			**o**	**x**
				Direction of membranes put down comparing to water flow directions	**1**	**0**									**x**
	Penetration details/choices	Error prone/ compromised roof's integrity (water tightness)	Insufficient knowledge/ not enough attention		**4**										
				Using pitched pan/collected boxes/grouping pipes reducing chances of leaks; too many causing problem-insufficient coating sealant	**2**	**0**				**x**				**x**	
				Satellite dish put directly on roof membranes; better put on frames with protective membranes	**1**	**0**							**x**		
				Using factory prefabricated booth for ventilation (error proof)	**1**	**0**			**x**						
	Material/ system compatibility choices	Error prone/ compromised roof's integrity (water tightness)	Insufficient knowledge/ not enough attention		**9**										
				Compatibility of roof types and geographical regions-some roofs are suitable for some regions	**1**	**0**					**x**				
				Compatibility of materials and applications; building uses and roof applications; construction means and roof systems	**5**	**1**		**x**		**x**	**x**		**x**	**x**	**o**

Table C.1 (Continued)

Phases	Descriptions (problems caused from ...)	Results lead to leak	Causes	Samples/reasons/activities	Total	Disagree	1	2	3	4	5	6	7	8	9
				Attachment systems-how components put together (membranes to membranes, membrane to substrate-some systems better than others)	5	0	x	x	x	x		x			
				Compatibility of roof decks and insulation and membranes	2	1						x		x	o
				Concepts of whole systems; all using roof manufacturer recommended components	1	0							x		
	Insufficient design criteria	Error prone/ compromised roof's integrity (water tightness)	Insufficient knowledge/ unfamiliar with the systems		3										
				Lack of thorough design criteria (wind uplifting, wind zones, surrounding, R & U Values)	1	0						x			
				Not meeting code compliance (100 years of rain records, R or U values)	3	0			x	x		x			
	Connected system on roofs (roof equipment/other components)	Error prone/ compromised roof's integrity (water tightness)	Lack of knowledge/ compatibility/ planning/ continuity		7										
				Amount of equipment (penetrations)	5	0					x	x	x	x	x
				Types of equipment (RTU; cooling towers, VTR)	1	0					x				
				Non-roof component -other building components related to roofs causing leaks (brick/foundation)	2	0			x					x	
				Conditions of condensed water lines-collected or not	1	0							x		
				Patterns of RTU-affecting drainage flow and accumulations on particular spots	1	0							x		

Table C.1 (Continued)

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	Samples/reasons/activities	Total	Disagree	1	2	3	4	5	6	7	8	9
				Curb heights-at least 8-12 inches	**2**	**0**							**x**	**x**	
				RTU needing curbs or platforms	**1**	**0**				**x**					
	Too much/little owner involvement	Compromised roof's integrity (water tightness)	Owner involvement		6										
				Owner's requirements (cheap, fast built, green, white)	**2**	**0**		**x**				**x**			
				Budgets dictating roof types/systems	**5**	**0**					**x**	**x**	**x**	**x**	**x**
				Durations of roof use (expected use life)-dictating roof types	**3**	**0**					**x**	**x**	**x**		
				Lack of input from owners/facility department	**1**	**0**								**x**	
Installation															
	Installation errors caused from details/design	Compromised roof's integrity (water tightness)	Detail errors/complicated details		5										
				Installer installation errors due to complicated details (improper terminating gutters where elevation changing, metal edge termination details-draped vinyl on the top of the roof)	**2**	**0**	**x**					**x**			
				Complex/customized details used	**4**	**0**	**x**			**x**	**x**				**x**
				Difference between actual space provided and details	**1**	**0**	**x**								
	Installation errors caused from installers	Compromised roof's integrity (water tightness)	Improper installation/ did not follow or pay attention to instruction		8										
				Improper installation-in general	**3**	**0**				**x**			**x**	**x**	
				C**aulking/sealant (**especially penetration areas)	**3**	**0**	**x**		**x**					**x**	

Table C.1 (Continued)

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	Samples/reasons/activities	Total	Disagree	1	2	3	4	5	6	7	8	9
				Membrane **attachment-**improper gluing to substrates	**3**	**0**	**x**	**x**			**x**				
				Gap/open laps in seams-membranes to membranes needed to roll correctly	**2**	**0**			**x**		**x**				
				Flashing (around equipment); mis-flashing-causing falling counter flashing and exposed curbs	**5**	**0**	**x**		**x**		**x**		**x**	**x**	
				Improper **terminating** membranes/flashings-allowing water to entry via gaps	**1**	**0**								**x**	
				D**rainage-**improper sloping insulation for drainage purposes; setting up internal drains higher than field levels	**1**	**0**	**x**								
				Fasteners-mis-fastened terminal bars on wall; not enough fasteners to withstand wind uplifting; fastener head improper embedding	**4**	**0**	**x**		**x**		**x**				**x**
				Insulation-causing moisture on the back of membranes	**2**	**0**			**x**				**x**		
				Not enough overlap membranes	**1**	**0**				**x**					
				Lack of site/material preparation-lack of cleaning before attaching to substrates, lack of membrane resting time before installing	**4**	**0**	**x**		**x**	**x**	**x**				
	Installation errors caused from environment	Error prone/ compromised roof's integrity (water tightness)	Environment		4										
				Installation time of year (months) due to weather	**4**	**0**			**x**	**x**			**x**	**x**	
				Improper installation due to speed of the project	**1**	**0**			**x**						
				Improper installation due to inadequate working space, dirt, other trades involved	**2**	**0**			**x**	**x**					

Table C.1 (Continued)

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	Samples/reasons/activities	Total	Disagree	1	2	3	4	5	6	7	8	9
				Improper installation due to lack of drawings, plans, specifications	**2**	**0**			**x**				**x**		
				Improper installation at lap/seams due to equipment conditions-not right temperature	**1**	**0**			**x**						
	Lack of quality crews	Error prone/ compromised roof's integrity (water tightness)	Crew quality		8										
				Lack of a good quality crew (correct design details but bad installation quality)	**6**	**0**				**x**	**x**	**x**	**x**	**x**	**x**
				Crews unfamiliar with the systems-using improper materials: reinforced vs. non-reinforced); lack of experience-not able to make on-site adjustment	**5**	**0**		**x**	**x**			**x**		**x**	**x**
				Installers' attitudes (this is the way we do work here, not follow instruction strictly)-improper installation based on good practice; crews need to pay attention to details	**6**	**0**		**x**			**x**	**x**	**x**	**x**	**x**
	Physical damages	Damaged materials/ compromised roof's integrity (water tightness)	Human working on roofs	Damages during construction	**3**	**0**		**x**	**x**		**x**				
	Lack of construction administration	Error prone/ compromised roof's integrity (water tightness)	Lack of quality control		7										
				No inspections/QC due to budget constrain	**4**	**0**		**x**				**x**	**x**		**x**

Table C.1 (Continued)

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	Samples/reasons/activities	Total	Disagree	1	2	3	4	5	6	7	8	9
				Lack of independent inspectors to control the roof quality	1	0						x			
				Lack of construction administrative	2	0					x			x	
				Lack of roof consultants	2	0			x			x			
Environment															
	Age	Deteriorated materials	Age	Aged materials; loss elasticity due to age	3	0	x		x					x	
	Local setting (micro-environment)	Physical damages	Local setting (micro-environment)	Tree limp/debris clogging drain or inhibiting the flow of water; foreign objects falling on roofs due to locations and surrounding of roofs	4	0	x		x		x			x	
	Weather patterns	Deteriorated materials/ physical damages	Weather patterns	Weather/temperature-uncontrollable; weather patterns in the South-not a problem	1	1				x	o				
	Environment-induced damages	Physical damages	Environment		6										
				Hail	2	0	x	x							
				Lightning	2	0			x						x
				Animals/insects (beetles, ants, seagull, squirrels)	4	0			x		x			x	x
				Wind (moving sharp objects/debris on roofs)	2	0	x		x						
				Snow on roof -too heavy	1	0	x								

Table C.1 (Continued)

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	Samples/reasons/activities	Total	Disagree	1	2	3	4	5	6	7	8	9
	Temperature/heat	Damage/deteriorated materials	Temperature/heat		7										
				Membranes/flashing degradation due to exposure to sun/UV-especially thermoplastics; dry caulk causing caulking failures; shrinkage lead to membrane deterioration	5	0	x	x	x		x	x			
				Material/component movement due to temperature -structure move (deck and insulation)	3	0				x		x			x
				Backing out fasteners; bake membranes from heat transferring from inside due to temperature	2	0			x			x			
Others															
	Material defects	Compromised roof's integrity (water tightness)	Manufacturer's problems												
				Material defects (less degrees) due to bad components/formula; roll setting up improperly during manufacturing; holes in membranes during manufacturing	3	2	x	x	x		o			o	
	Industry problems	Error prone/ compromised roof's integrity (water tightness)	Industry problems		4										
				Lack of testing information available; lack of material histories (material performances)	3	0		x		x		x			
				Poor details or too generic details available	1	0						x			
				No accountable parties for roof problems (manufacturers or designers)	1	0						x			

Table C.1 (Continued)

Phases	Descriptions (problems caused from …)	Results lead to leak	Causes	Samples/reasons/activities	Total	Disagree	1	2	3	4	5	6	7	8	9
				Roof design taking roofs as a non-serious design matter both in real life and school	**2**	**0**					**x**	**x**			
	System weak-points	Error prone/ compromised roof's integrity (water tightness)	System weak-points		9										
				Weak-points-disaggregated areas (lap seams/penetrations/ multi-layers/flashings); areas where flexibility needed; time to cure and preparation before installation; the ways seams constructed (where installers need to stop and work at the penetration)	**8**	**0**	**x**	**x**	**x**	**x**	**x**		**x**	**x**	**x**
				Inherent weak-points (punctures/tears); single-ply not suitable for many penetrations; substantial foot traffic; equipment needed maintenance	**6**	**0**		**x**			**x**	**x**	**x**	**x**	**x**
				Weak-point - prone to shrinkage	**1**	**0**						**x**			
				Lack of water tightness redundancy	**1**	**0**						**x**			

APPENDIX D

Collinearity Diagnostics

Table D.1 Collinearity Diagnostics Table

Dimension	Eigenvalue	Condition Index	Variance Proportions																					
			(Constant)	AG	RA	EP	WE	TE	DT	DD	DDN	SU	WS	WX	PR	PS	RH	EM	RI	RR	IS	CZ	MT	WC	LS
1	5.49	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
2	3.11	1.33	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	2.82	1.40	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
4	1.91	1.69	0.00	0.01	0.03	0.02	0.07	0.00	0.01	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.04	0.00	0.00	0.00	0.00	0.00
5	1.74	1.78	0.00	0.00	0.02	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.07	0.07	0.00	0.00	0.00	0.00	0.00
6	1.48	1.92	0.00	0.10	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.11	0.00	0.01	0.00	0.00	0.00	0.00	0.00
7	1.20	2.14	0.00	0.01	0.19	0.02	0.00	0.00	0.07	0.00	0.19	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
8	0.99	2.35	0.00	0.00	0.20	0.03	0.00	0.00	0.04	0.02	0.12	0.00	0.01	0.03	0.01	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00
9	0.88	2.50	0.00	0.00	0.00	0.07	0.01	0.00	0.28	0.01	0.11	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.12	0.04	0.00	0.00	0.00	0.00	0.00
10	0.71	2.77	0.00	0.00	0.10	0.00	0.03	0.00	0.22	0.01	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.54	0.01	0.00	0.00	0.00	0.00	0.00
11	0.56	3.15	0.00	0.24	0.06	0.16	0.00	0.00	0.09	0.03	0.02	0.00	0.02	0.02	0.06	0.00	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.00	0.00
12	0.41	3.67	0.00	0.02	0.23	0.15	0.03	0.00	0.04	0.12	0.17	0.00	0.00	0.01	0.00	0.00	0.08	0.21	0.01	0.04	0.00	0.00	0.00	0.00	0.00
13	0.39	3.76	0.00	0.16	0.01	0.07	0.03	0.00	0.02	0.13	0.05	0.00	0.00	0.01	0.02	0.00	0.02	0.43	0.04	0.10	0.00	0.00	0.00	0.00	0.00
14	0.32	4.12	0.00	0.01	0.00	0.00	0.70	0.00	0.03	0.05	0.01	0.00	0.00	0.01	0.01	0.00	0.05	0.01	0.01	0.57	0.00	0.00	0.00	0.00	0.00
15	0.30	4.26	0.00	0.01	0.11	0.36	0.02	0.00	0.08	0.01	0.06	0.00	0.08	0.19	0.06	0.01	0.13	0.01	0.08	0.04	0.00	0.00	0.00	0.00	0.00
16	0.19	5.34	0.00	0.04	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00	0.02	0.07	0.11	0.00	0.06	0.01	0.00	0.00	0.63	0.00	0.01	0.01	0.01
17	0.16	5.79	0.00	0.01	0.02	0.00	0.02	0.00	0.03	0.00	0.11	0.01	0.08	0.37	0.54	0.00	0.18	0.01	0.02	0.01	0.19	0.00	0.01	0.00	0.00
18	0.13	6.46	0.00	0.05	0.00	0.00	0.01	0.01	0.03	0.00	0.05	0.04	0.16	0.04	0.01	0.69	0.00	0.08	0.03	0.01	0.00	0.00	0.00	0.02	0.02
19	0.08	8.19	0.00	0.16	0.00	0.04	0.00	0.00	0.00	0.05	0.01	0.03	0.07	0.00	0.00	0.08	0.00	0.00	0.01	0.01	0.03	0.00	0.03	0.23	0.39
20	0.04	11.28	0.01	0.06	0.00	0.02	0.01	0.01	0.00	0.01	0.00	0.08	0.00	0.01	0.00	0.02	0.05	0.00	0.00	0.02	0.02	0.04	0.21	0.47	0.32
21	0.03	13.77	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.09	0.02	0.01	0.00	0.03	0.08	0.00	0.00	0.00	0.05	0.12	0.64	0.13	0.17
22	0.02	15.96	0.05	0.08	0.00	0.00	0.01	**0.59**	0.02	0.37	0.02	**0.71**	0.42	0.14	0.00	0.13	0.29	0.00	0.02	0.00	0.03	0.01	0.01	0.12	0.05
23	0.01	31.91	0.92	0.02	0.01	0.03	0.00	**0.37**	0.00	0.15	0.03	0.00	0.09	0.02	0.10	0.00	0.00	0.00	0.01	0.00	0.03	**0.83**	0.08	0.01	0.03
Dependent Variable: Leaks																									

APPENDIX E

Logistic Regression

A brief description of logistic regression analysis is presented in the following sections using a number of sources (Hosmer and Lemeshow 2000; Chapter 12 in Tabachnick and Fidell 2000; Chapter 5 and 6 in Field 2005; Garson 2006).

Logistic Regression

Binomial logistic regression is a multiple regression with a categorical binary outcome and continuous or categorical predictor variables. This distinguished feature, dichotomous outcomes, violates the linear relationship assumed by the linear regression. The logistic regression overcomes this problem by transforming the data into a logit variable (the natural log of the odds of the dependent occurring or not) using logarithmic transformation to express a non-linear relationship in a linear way (Field 2005).

The logistic analysis methods, for the most part, are the same as general principles used in linear regression (Hosmer and Lemeshow 2000). The goal of a logistic analysis, as any statistical model-building technique, is to find the best-fitting model to describe the relationship between the outcome and predictors. Not only can it determine the percent of variance in the dependent variable explained by the independents, the logistic can also rank the relative importance of independents, assess interaction effects, and describe the impact of covariate (Garson 2006).

When the response variable is binary, or a binomial proportion, the shape of the expected response is often a curve. The S-shaped curve shown below is known as the logistic curve (Stephenson 2007).

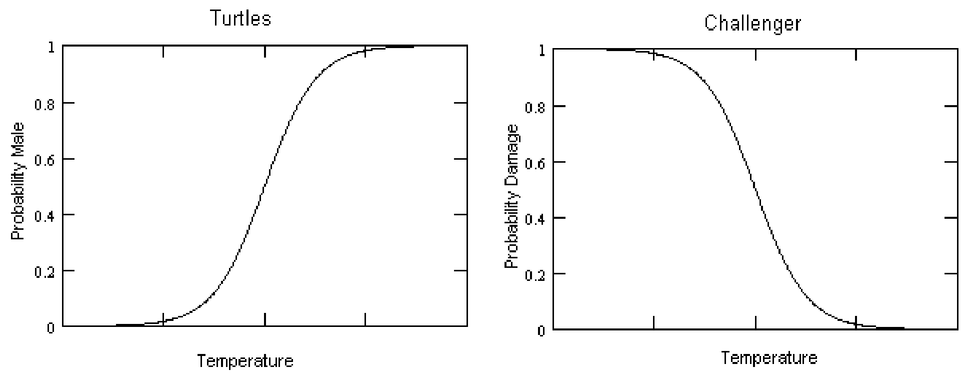

Figure E.1 Increasing and Decreasing Logistic Plots (Stephenson 2007)

Fundamental Equations

The logistic regression equation bears many similarities to multiple regression. However, instead of predicting the outcome value, as in linear regression, the logistic regression estimates the probability of a certain event occurring based on a nonlinear function of the best linear combination of predictors. The probability of an event occurring can be calculated using the following equation.

$$\text{Probability (P) (event (Y))} = \frac{1}{1+e^{-Z}} \qquad \text{(Equation E.1)}$$

where Z is the linear equation expression in Equation E.2.
e is the base of the natural logarithms
Probability (P) (event(Y)) is the predicted probability that an event occurs

$$Z = B_0+B_1X_1+B_2X_2+\ldots B_pX_p \qquad \text{(Equation E.2)}$$

$B_0 \ldots B_p$ are coefficients (logits) estimated from the data
$X_1 \ldots X_p$ are independent variables
p is the number of independent variables

The result from Equation 7.1 is a probability value that varies between 0 and 1. A value close to 0 means the outcome is very unlikely to occur, and a value close to 1 means the outcome is likely to occur. Generally, the cutting point value for the prediction is 0.5.

Similar to linear regression "b-coefficient", each predictor variable in the logistic model has its own coefficients, "logit coefficients (logits)" or "parameter estimates", from fitting models to the observed data using the maximum likelihood technique. The maximum likelihood estimation works in an iterative manner to determine directions and sizes of change in the coefficients. The goal of this process is to find the best linear combination of predictors to maximize the likelihood of obtaining the observed outcome frequencies (Tabachnick and Fidell 2000).

The success of the logistic regression can be assessed based on the percentage of correctly classified groups of members on a classification table. The goodness-of-fit test, model chi-square, is also an indicator of model appropriateness, while Wald statistic indicates the significance of individual independent variables.

Benefits and Limitations

Logistic regression is related to and can answer the same question as many other statistical analysis functions, such as discriminate function analysis, multi regression analysis, and multi-way frequency analysis. Unlike these statistical techniques, logistic regression has less stringent requirements and is more flexible (Tabachnick and Fidell 2000; Garson 2006). Logistic regression does not have assumptions about the predictor variable distributions, such as in discriminant function or multiple regression analysis. The predictors in logistic regression do not have to be normally distributed, linearly related, or of equal variance within each group. Unlike multi-way frequency analysis, which requires predictors to be discrete (Tabachnick and Fidell 2000), in logistic regression, they can mix between continuous, discrete and dichotomous variables.

However, Tabachnick and Fidell (2000) outline a number of concerns with logistic regression analysis.

1. *Ratios of cases to variables:* When there are too few cases relative to the number of predictor variables or a complete separation of group, the logistic regression analysis can result in high parameter estimates and standard errors. Many researchers suggest a minimum ratio between cases and independent variables as 10:1 (Peduzzi, Concato et al. 1996; Hosmer and Lemeshow 2000; Garson 2006). Garson further suggests that, in a case where there are categorical independents, the number to be considered should be the smallest of the group; Peduzzi, Concato et al. suggest using the lesser group of dependent variables as the number of cases.

2. *Adequacy of expected frequencies and power:* The analysis of goodness-of-fit may have little power if expected frequencies are too small.

3. *Linearity in the logit:* Logistic regression analysis requires observations to be independent and that the logit of the independent variables is linearly related to the dependent (Garson 2006).

4. *Absence of multicollinearit*y: Like other regressions, logistic regression is sensitive to extremely high correlations among predictor variables, which is signaled by exceedingly high standard errors for parameter estimates and/or failure of a tolerance test.

5. *Absence of outliers in the solution:* One or more of the outlier cases may cause a very poor predicting solution. Outliers can, nevertheless, be avoided by examining the residuals.

Methods of Logistic Regression

There are several methods used in logistic regression, which are discussed in the following section.

1. *Direct Logistic Regression (forced entry method)*

In direct logistic regression, all predictors enter the equation simultaneously. Each predictor is evaluated as it is entered into the equation. This is the default method in many statistical packages and used generally when there is no specific hypotheses about the order or importance of predictor variables.

2. *Sequential Logistic Regression*

In sequential logistic regression, the order of predictor entries can be specified based on previous work or other experiments. After known predictors have been entered, additional predictors can be added into the model and tested for their significance.

3. *Stepwise Logistic Regression*

This is considered a screening or hypothesis-generating technique. In this method, inclusion or removal of predictors from the equation is solely based on statistical criteria and computation, and, therefore, criticized by many researchers. Some experts believe that automated methods did not produce the best model; however, Field believed it was suitable for exploratory model building (Field 2005). Therefore, derived models need to be interpreted with caution (Tabachnick and Fidell 2000; Norusis 2005).

Any stepwise procedure for selection or deletion of variables from a model is based on a statistical algorithm that checks for the importance of variables. The importance is a measure of the statistical significance of the coefficient of the variable and is assessed via the likelihood ratio chi-square test.

There are two types of stepwise logistic regression, forward and backward stepwise. In the forward method, an initial model or model containing only the constant, searches for the predictor that has the most-significant score statistic. The computer proceeds until none of the remaining predictors have a significant score statistic. Every time a predictor is added into the model, a removal test is also performed to remove the least-useful predictor. The predictor will be retained if it makes a significant difference in how well the model fits the observed data. In this case, the model is constantly adjusted and reassessed.

The backward stepwise logistic regression begins the process in an opposite direction. All predictors are placed in the model and the SPSS tests whether any predictors can be removed without substantially affecting how well the model fits the observed data. If the predictor meets the removal criteria, it will be removed and the model re-estimated for the remaining predictors. The process will stop when none of remaining variables meet the removal criteria.

Assessing the Model

1. The Log Likelihood

Likelihood is the probability (0 to 1) that the observed values of the dependent can be predicted from the observed values of the independents. The log likelihood (LL) varies from 0 to minus infinity (log of any number less than 1 is negative). The log likelihood is based on summing the probabilities associated with the predicted and actual outcome, as shown in Equation 7.3 (Field 2005). It is analogous to the residual sum of square in multiple regression, since it indicates how much unexplained information remains after the model has been fitted. The larger the log likelihood, the more unexplained observations there are. The LL is calculated through iteration using maximum likelihood estimation.

$$\text{Log-likelihood} = \sum_{i=1}^{N}\{Yi\ln(P(Yi)) + (1 - Yi)\ln[1 - P(Yi)]\} \qquad \text{(Equation E.3)}$$

$P(Yi)$ = the probability that Y occurs for the i^{th} case
Yi = the actual outcome for the i^{th} case
In = the natural logarithm where ln x = $\log_e$ x

In logistic regression analysis, the log likelihood test, sometimes called model chi-square, is also used to test the significance of a derived logistic model. The process starts by comparing the difference in log likelihoods and chi-square between two models, the simplest (only the constant) and the most complex (the constant and predictors). If the chi-square distribution (χ^2) is reliable at $\alpha = .05$, the model with predictors is said to be better than the one with only a constant.

2. R-square

Two R^2-like measures, Cox & Snell's R-square and Nagelkerke's R-square, are approximated to R^2 and interpreted in the same way as in linear regression (Field 2005). The higher the R-square, the more predictors explain the outcome. Garson, however, suggests that these measures are not goodness-of-fit test; rather, they only attempt to measure strength of association (2006).

Cox and Snell's R-square attempts to imitate the interpretation of multiple R-square based on the log likelihood of the model (new and baseline). However, its maximum can be less than 1.0 and make it difficult to interpret (Garson 2006)

Negelkerke's R-square is a modification of the Cox and Snell coefficient to assure the result is between 0 and 1. Nagelkerke's R-square is normally higher than the Cox and Snell measure, but tends to be lower than the corresponding R^2 in linear regression.

3. Classification Table

The 2x2 tables measures the model's ability to correctly predict the group of memberships. In a perfect model, all cases will be on the diagonal and the overall percent correct will be 100%. The higher the percentage, the better the model. If the logistic model has homoscededsticity, both numbers will be approximately the same. Garson, however, suggests that this test should not be used to substitute goodness-of-fit measures, due to the fact that it does not reveal how close or far the prediction is from 0 or 1 (Garson 2006).

4. By-Chance Accuracy

To evaluate the usefulness of the logistic model, the full model (model with interested variables) should improve by at least 25% over the rate of accuracy achieved by chance alone. The by-chance accuracy was defined by the correct prediction of group members in which independent variables have no relationship with dependent variables (Schwab 2006).

Assessing the Contribution of Predictor

1. Wald Statistic (test)

The Wald statistic, with chi-square distribution, is used to test the significance of individual independent variable logits. It tells whether or not a particular logit (effect) coefficient for a predictor is significantly different from zero. This corresponds to the t-statistic in linear regression. If the coefficient is significantly different from 0 (p <.05), then that predictor is making a significant contribution to the prediction of the outcome (Field 2005). The Wald statistics test is calculated by dividing the regression coefficient by its associate standard error. Garson suggests that, to make certain global statements about the significance of an independent variable, both the correlation and the logit should be significant (2006). Type II errors (false negative) can occur when large logits are detected (Menard 1995).

2. A Unit Change in Predictor (Exp (B))

The change in odds resulting from a unit change in the predictor (Exp (B)) is crucial to the interpretation of logistic regression. The odds of an event occurring are defined as probability of an event occurring divided by the probability of that event not occurring, as shown in Equation E.4. The value of exp B greater than 1 indicates that as the predictor increases, the odds of the outcome occurring increase.

$$\text{Odds of event occurring} = \frac{\text{Probability (event occurring)}}{\text{Probability (no event occurring)}} \qquad \text{(Equation E.4)}$$

The change of odds resulting from a unit change of predictor variable can be calculated using the following equation.

$$\text{Change of odds} = \frac{\text{Odds after a unit change in the predictor}}{\text{Original odds}} \qquad \text{(Equation E.5)}$$

Excerpt from (Garson 2006)

The most common way of interpreting a logit is to convert it to an odds ratio using the exp() function; it can convert back using the ln() function. For instance, if the logit b_1 = 2.303, then the corresponding odds ratio (the exponential function, e^b) is 10, then it can say that when the independent variable increases one unit, the odds that the dependent = 1 increase by a factor of 10, when other variables are controlled. In SPSS, odds ratios appear as "Exp(B)" in the "Variables in the Equation" table. Warning: The statement about odds and probabilities are not the same.

2.1 Confidence interval on the odds ratio

SPSS labels the odds ratio "Exp(B)" and prints "Low" and "High" confidence levels for it. When the 95% confidence interval around the odds ratio includes the value of 1.0, indicating that a change in value of the independent variable is not associated in change in the odds of the dependent variable assuming a given value, then that variable is not considered a useful predictor in the logistic model.

2.2 Percent increase in probability

Sometimes the researcher wishes to express the meaning of logistic regression coefficients in terms of probabilities rather than changes in odds. Suppose the original probability of the dependent was 15%. This corresponds to an odds of 15/85 = .176. Suppose the logistic coefficient is .4. This corresponds to an odds ratio of $e^{.4}$ = 1.49. Thus the odds of .176 multiplied by the odds ratio of 1.49 = a new odds of the dependent of .263. Let x be the new probability. We know x/(1-x) = .263 since the odds are defined as the probability divided by the not-probability (which is thus 1-x). Solving for x, we get x = .21. Thus for an original probability of 15%, a logistic b coefficient of .4 means that a unit increase in that variable increases the probability to 21%, for an increase of 6%. If passing a test is the dependent and age is the independent, the researcher would thus say, "An increase of 1 year in age increases the chance of passing the test by 6%, controlling for other variables in the model."

Calculation Sample

Assume other variables are hold at it mean and roof at 5^{th} month has 15% probability of leak

This corresponds to an odds of 15/85 = .176 (Equation E.4)

From equation 4.1, the logit of age is 3.355 this corresponds to an odds ratio of

$$e^{3.355} = 28.641$$

Thus the new odds of the leak is 0.176*28.641 = 5.0408

Let x be the new probability

x /(1-x) = 5.0408

x = .8344 (83%)

Original Probability 15%, New Probability 83%, therefore an increasing of Probability =

68%

Note:
When original probability is 50%, the new probability is 97% (an increase of 47%)
When original probability is 80%, the new probability is 99% (an increase of 19%)

APPENDIX F

ADDITIONAL LOGISTIC REGRESSION TRAILS

All main variables but maintenance records (RI and RR) (comparable to Trial 1 in Chapter 4)

Omnibus Tests of Model Coefficients

	Chi-square	df	Sig.
Model	241.409	27	.000

Model Summary

-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
155.500	.541	.749

Classification Table

Observed		Predicted		
		Leaks		(%)Correct
		No Leak	Leak	
Leaks	No Leak	86	19	81.9
	Leak	9	196	95.6
Overall Percentage				91.0

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
ZAG	2.200	.397	30.669	1	.000	9.029
ZRA	-.125	.253	.244	1	.621	.882
ZEP	-.279	.321	.753	1	.385	.757
ZWE	3.315	.517	41.158	1	.000	27.509
ZTE	-1.755	1.291	1.848	1	.174	.173
ZDT	-.197	.240	.678	1	.410	.821
ZDD	-.626	.426	2.152	1	.142	.535
ZDDN	-.150	.229	.425	1	.514	.861
ZSU	.230	.810	.081	1	.776	1.259
ZWS	-.868	.544	2.547	1	.110	.420
ZWX	.452	.399	1.284	1	.257	1.572
ZPR	-.352	.475	.549	1	.459	.703

Figure F.1 Additional Trial 1 Results

	B	S.E.	Wald	df	Sig.	Exp(B)
ZPS	.629	.625	1.012	1	.314	1.876
ZRH	-.406	.449	.816	1	.366	.667
ZEM	.402	.329	1.493	1	.222	1.495
IS			2.934	3	.402	
IS(1)	-.337	.658	.262	1	.609	.714
IS(2)	.096	.702	.019	1	.892	1.100
IS(3)	.715	.732	.955	1	.329	2.044
CZ			6.612	4	.158	
CZ(1)	-4.533	2.233	4.120	1	.042	.011
CZ(2)	-3.540	1.843	3.690	1	.055	.029
CZ(3)	-1.406	1.539	.835	1	.361	.245
CZ(4)	-.722	1.046	.477	1	.490	.486
MT(1)	.417	1.303	.103	1	.749	1.518
WC(1)	-.329	1.000	.108	1	.742	.720
LS			3.040	3	.386	
LS(1)	-.852	1.184	.518	1	.471	.426
LS(2)	.298	.801	.139	1	.709	1.348
LS(3)	-.507	.772	.430	1	.512	.602
Constant	4.035	1.463	7.606	1	.006	56.540

Figure F.1 (Continued)

All main variables but maintenance records (RI and RR) (comparable to Trial 3 in Chapter 4)

Omnibus Tests of Model Coefficients

	Chi-square	df	Sig.
Model	220.164	2	.000

Model Summary

-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
176.745	.508	.704

Classification Table

Observed		Predicted		
		Leaks		(%) Correct
		No Leak	Leak	
Leaks	No Leak	79	26	75.2
	Leak	12	193	94.1
Overall Percentage				87.7

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
ZAG	2.051	.284	52.164	1	.000	7.774
ZWE	2.960	.429	47.610	1	.000	19.294
Constant	1.790	.264	45.924	1	.000	5.990

Figure F.2 Additional Trial 2 Results

Main effect and 2-way interaction predictors but maintenance records (RI and RR) (comparable to Trial 5 in Chapter 4)

Omnibus Tests of Model Coefficients

	Chi-square	df	Sig.
Model	264.474	14	.000

Model Summary

-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
132.435	.574	.795

Classification Table

Observed		Predicted		
		Leaks		(%) Correct
		No Leak	Leak	
Leaks	No Leak	90	15	85.7
	Leak	10	195	95.1
Overall Percentage				91.9

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
ZAG	1.683	.888	3.588	1	.058	5.381
ZWE	5.239	1.217	18.534	1	.000	188.423
ZTE	-1.086	.347	9.808	1	.002	.337
ZAG by ZEP	.917	.418	4.812	1	.028	2.501
ZAG by ZTE	.438	.289	2.295	1	.130	1.550
ZAG by ZRH	-1.616	.613	6.939	1	.008	.199
LS * ZAG			5.531	3	.137	
LS(1) by ZAG	1.525	1.530	.994	1	.319	4.597
LS(2) by ZAG	2.328	1.170	3.957	1	.047	10.256
LS(3) by ZAG	.414	.963	.185	1	.667	1.512
ZWE by ZTE	-1.379	.528	6.820	1	.009	.252
LS * ZWE			5.000	3	.172	
LS(1) by ZWE	4.738	3.101	2.335	1	.127	114.252
LS(2) by ZWE	-1.403	1.197	1.374	1	.241	.246
LS(3) by ZWE	-.737	1.144	.416	1	.519	.478
ZRH by ZEM	1.191	.483	6.090	1	.014	3.290
Constant	3.000	.501	35.796	1	.000	20.077

Figure F.3 Additional Trial 3 Results

Main effect and 2-way interaction predictors but maintenance records (RI and RR) (comparable to Trial 7 in Chapter 4)

Omnibus Tests of Model Coefficients

	Chi-square	df	Sig.
Model	287.960	18	.000

Table F.4b Model Summary

-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
108.949	.605	.838

Classification Table

Observed		Predicted		
		Leaks		(%)Correct
		No Leak	Leak	
Leaks	No Leak	94	11	89.5
	Leak	8	197	96.1
Overall Percentage				93.9

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
ZAG	2.041	.784	6.772	1	.009	7.700
ZWE	6.016	.939	41.051	1	.000	409.921
ZPS	.973	.442	4.855	1	.028	2.646
ZAG by ZTE	1.162	.473	6.041	1	.014	3.196
ZAG by ZRH	-1.647	.473	12.141	1	.000	.193
LS * ZAG			12.681	3	.005	
LS(1) by ZAG	.288	1.100	.068	1	.794	1.333
LS(2) by ZAG	3.870	1.173	10.893	1	.001	47.939
LS(3) by ZAG	.785	.884	.788	1	.375	2.192
ZRA by ZWS	-1.688	.640	6.965	1	.008	.185
ZEP by ZDDN	1.773	.507	12.215	1	.000	5.889
ZEP by ZWX	-1.909	.487	15.374	1	.000	.148
ZWE by ZTE	-1.821	.598	9.281	1	.002	.162
ZWE by ZPR	1.193	.462	6.680	1	.010	3.296
ZTE by ZSU	-1.104	.424	6.778	1	.009	.332
ZDT by ZWX	.892	.453	3.882	1	.049	2.441
ZDDN by ZRH	1.007	.337	8.919	1	.003	2.738

Figure F.4 Additional Trial 4 Results

Variables in the Equation (Continue)

	B	S.E.	Wald	df	Sig.	Exp(B)
WC(1) by ZPR	3.992	1.530	6.803	1	.009	54.146
WC(1) by ZPS	5.352	2.336	5.250	1	.022	211.125
Constant	4.905	.834	34.609	1	.000	135.006

Figure F.4 (Continued)

APPENDIX G

Internal Validation Results

k=10

Table G.1 Internal Validation k=10

Model#	Training case	Hold out case	Training accuracy (%)	Hold out accuracy (%)
101	265	38	93.2	84.2
102	268	35	91.8	97.1
103	274	29	92.0	96.6
104	278	25	92.1	92.0
105	273	30	92.3	86.7
106	280	23	92.5	82.6
107	268	35	92.2	91.4
108	267	36	92.1	91.7
109	278	25	91.4	96.0
1010	279	24	92.1	95.8
Average Accuracy			92.2	91.4
Average Misclassify			7.8	8.6

k=5 (first trial)

Table G.2 Internal Validation k=5 (first trial)

Model#	Training case	Hold out case	Training accuracy (%)	Hold out accuracy (%)
5A	245	58	92.7	93.1
5B	248	55	92.7	87.3
5C	244	59	93.0	89.8
5D	245	58	92.2	93.1
5E	230	73	90.9	94.5
Average Accuracy			92.3	91.6
Average Misclassify			7.7	8.4

k=5 (second trial)

Table G.3 Internal Validation k=5 (second trial)

Model#	Training case	Hold out case	Training accuracy (%)	Hold out accuracy (%)
51A	251	52	91.6	96.2
51B	237	66	94.1	86.4
51C	228	75	91.2	96.0
51D	245	58	91.8	91.4
51E	252	51	93.3	86.3
Average Accuracy			92.4	91.3
Average Misclassify			7.6	8.7

k=5 (third trial)

Table G.4 Internal Validation k=5 (third trial)

Model#	Training case	Hold out case	Training accuracy (%)	Hold out accuracy (%)
52A	225	78	92.0	91.0
52B	241	62	92.1	91.9
52C	253	50	91.3	96.0
52D	245	58	93.1	89.7
52E	249	54	92.4	92.6
Average Accuracy			92.2	92.2
Average Misclassify			7.8	7.8

APPENDIX H

External Validation: Linear Regression Values

Table H.1 Linear Regression Values

ID	Age	Workmanship	Roof Repair	Constant	Linear Regression Value
1	-3.27477	5.07331	1.72998	3.64700	7.17552
2	-6.58262	-9.16172	1.72998	3.64700	-10.36736
3	-2.61320	-7.53654	1.72998	3.64700	-4.77276
4	-2.61320	-7.53654	1.72998	3.64700	-4.77276
5	-2.94399	-5.89178	1.72998	3.64700	-3.45878
6	-3.27477	-2.03442	1.72998	3.64700	0.06779
7	-1.95163	-5.89178	1.72998	3.64700	-2.46643
8	-3.60556	-3.28757	-2.38412	3.64700	-5.63025
9	-2.28242	-4.26659	1.72998	3.64700	-1.17203
10	0.69465	-5.89178	1.72998	3.64700	0.17985
11	0.36386	0.62853	1.72998	3.64700	6.36938
12	1.35622	3.89848	1.72998	3.64700	10.63168
13	0.03308	7.14885	1.72998	3.64700	12.55891
14	-2.28242	-7.53654	1.72998	3.64700	-4.44198
15	-2.28242	-0.99665	1.72998	3.64700	2.09792
16	0.69465	-9.16172	-0.03908	3.64700	-4.85916
17	0.69465	3.89848	1.72998	3.64700	9.97011
18	1.35622	-0.99665	1.72998	3.64700	5.73655
19	4.00250	-7.53654	0.49575	3.64700	0.60871
20	4.33328	-5.89178	-0.69734	3.64700	1.39116
21	4.33328	-2.64141	1.72998	3.64700	7.06885
22	3.67171	0.62853	1.72998	3.64700	9.67723
23	-2.61320	0.62853	-1.43788	3.64700	0.22445
24	-2.94399	-7.53654	-1.68473	3.64700	-8.51825
25	-3.60556	4.54464	1.72998	3.64700	6.31606
26	-4.92869	3.89848	1.72998	3.64700	4.34677
27	-1.29006	-0.99665	-0.69734	3.64700	0.66295
28	-5.25948	18.25100	-6.49823	3.64700	10.14029
29	-5.59026	0.62853	1.72998	3.64700	0.41525
30	-2.28242	-5.89178	1.72998	3.64700	-2.79721
31	-5.92105	36.51962	1.72998	3.64700	35.97556
32	-2.61320	0.62853	-1.43788	3.64700	0.22445
33	-2.61320	-7.53654	-1.43788	3.64700	-7.94062
34	-1.62085	10.41879	-8.55528	3.64700	3.88967
35	-2.61320	-4.26659	-7.77360	3.64700	-11.00639
36	0.03308	0.62853	-2.17842	3.64700	2.13020
37	-2.61320	0.62853	-4.60574	3.64700	-2.94341
38	-0.95928	0.62853	1.72998	3.64700	5.04624
39	-0.29771	5.52366	-2.38412	3.64700	6.48883

Table H.1 (Continued)

ID	Age	Workmanship	Roof Repair	Constant	Linear Regression Value
40	-0.29771	-0.99665	-0.32707	3.64700	2.02557
41	2.67936	2.25372	1.72998	3.64700	10.31006
42	0.03308	0.62853	-0.24479	3.64700	4.06382
43	0.03308	-2.64141	-0.24479	3.64700	0.79388
44	-1.29006	-0.99665	1.72998	3.64700	3.09027
45	0.36386	-4.26659	-0.12137	3.64700	-0.37710
46	1.68700	-2.64141	1.72998	3.64700	4.42257
47	2.01779	-2.64141	0.20776	3.64700	3.23114
48	-0.95928	2.25372	-2.83667	3.64700	2.10477
49	5.32564	-2.64141	0.61917	3.64700	6.95040
50	4.33328	-5.89178	1.72998	3.64700	3.81848
51	5.65642	-2.64141	-0.45049	3.64700	6.21152
52	4.99485	0.62853	-1.68473	3.64700	7.58566
53	4.00250	2.25372	-0.77962	3.64700	9.12359
54	2.67936	-2.64141	1.72998	3.64700	5.41493
55	5.32564	0.62853	-0.49164	3.64700	9.10954
56	4.33328	3.89848	0.53689	3.64700	12.41565
57	5.98721	3.89848	-0.36821	3.64700	13.16448
58	2.67936	3.89848	1.72998	3.64700	11.95482
59	4.99485	5.52366	-1.68473	3.64700	12.48079
60	5.32564	10.41879	-2.71325	3.64700	16.67818

APPENDIX I

Estimated Service Life Prediction Values

Table I.1 ESL Derived from Single Value Factor Class and Arbitrary Coding

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor F	Factor G	ESL
164	5	g	7.00	5.00	5.00	1.00	1.00	175
170	-1		7.00	9.00	3.00	5.00	1.00	945
172	13	p	7.00	9.00	5.00	3.00	1.00	945
201	-1		7.00	9.00	1.00	5.00	3.00	945
374	12	p	7.00	9.00	3.00	5.00	1.00	945
375	9	p	7.00	7.00	3.00	3.00	3.00	1,323
376	-1		7.00	9.00	3.00	5.00	1.00	945
378	-1		7.00	9.00	3.00	5.00	1.00	945
379	6	g	7.00	9.00	3.00	5.00	1.00	945
380	-1		7.00	9.00	3.00	5.00	1.00	945
513	3	p	7.00	7.00	3.00	5.00	5.00	3,675
516	-1		7.00	9.00	1.00	5.00	5.00	1,575
518	4	p	7.00	7.00	3.00	5.00	1.00	735
735	1	p	7.00	1.00	5.00	5.00	1.00	175
740	27	g	7.00	9.00	5.00	5.00	1.00	1,575
742	2	g	9.00	5.00	5.00	5.00	1.00	1,125
743	1	p	7.00	5.00	5.00	7.00	7.00	8,575
744	10	p	7.00	7.00	5.00	5.00	1.00	1,225
745	6	p	7.00	9.00	5.00	5.00	3.00	4,725
805	23	g	9.00	9.00	5.00	3.00	1.00	1,215
808	4	p	7.00	7.00	3.00	3.00	3.00	1,323
809	12	g	7.00	9.00	5.00	5.00	1.00	1,575
810	-1		7.00	9.00	5.00	5.00	3.00	4,725
812	11	p	7.00	9.00	5.00	5.00	1.00	1,575
816	2	p	7.00	7.00	3.00	5.00	3.00	2,205
817	-1		7.00	9.00	3.00	5.00	1.00	945
888	14	p	7.00	9.00	5.00	5.00	1.00	1,575
963	-1		9.00	9.00	5.00	5.00	7.00	14,175
965	-1		7.00	9.00	5.00	7.00	3.00	6,615
984	13	p	9.00	9.00	5.00	5.00	3.00	6,075
1126	1	g	9.00	5.00	5.00	5.00	1.00	1,125
1129	1	p	7.00	9.00	5.00	5.00	1.00	1,575
1130	13	p	7.00	9.00	5.00	5.00	1.00	1,575
1262	26	g	7.00	9.00	7.00	7.00	5.00	15,435
1282	14	p	7.00	9.00	7.00	7.00	3.00	9,261
1405	4	g	7.00	7.00	5.00	5.00	1.00	1,225
1406	2	p	7.00	9.00	5.00	5.00	1.00	1,575
1407	5	p	7.00	7.00	3.00	5.00	3.00	2,205
1409	6	p	7.00	9.00	5.00	5.00	1.00	1,575
1410	3	g	7.00	7.00	5.00	3.00	1.00	735
1538	2	p	5.00	7.00	7.00	7.00	5.00	8,575
1540	11	p	3.00	9.00	7.00	5.00	5.00	4,725
1544	-1		3.00	9.00	7.00	5.00	1.00	945
1608	2	p	9.00	9.00	5.00	7.00	3.00	8,505
1754	19	p	7.00	9.00	5.00	3.00	1.00	945
1764	-1		7.00	9.00	5.00	3.00	1.00	945
1770	-1		7.00	9.00	3.00	7.00	1.00	1,323
1809	1	p	3.00	9.00	7.00	7.00	1.00	1,323
1810	-1		1.00	9.00	7.00	9.00	1.00	567
1943	-1		7.00	9.00	7.00	5.00	1.00	2,205
1948	2	p	7.00	7.00	7.00	7.00	1.00	2,401
1955	12	p	7.00	9.00	7.00	3.00	1.00	1,323
1956	3	p	7.00	9.00	7.00	5.00	1.00	2,205
1961	25	g	7.00	9.00	7.00	3.00	1.00	1,323

Table I.1 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor F	Factor G	ESL
1967	1	p	9.00	7.00	7.00	5.00	1.00	2,205
1976	-1		9.00	9.00	7.00	3.00	1.00	1,701
1978	11	p	9.00	9.00	7.00	5.00	1.00	2,835
1979	3	p	9.00	7.00	5.00	3.00	1.00	945
1980	3	p	7.00	7.00	7.00	5.00	1.00	1,715
1982	-1		7.00	9.00	7.00	5.00	1.00	2,205
1983	12	p	9.00	9.00	7.00	5.00	1.00	2,835
1987	10	p	9.00	7.00	7.00	5.00	1.00	2,205
1989	15	p	7.00	9.00	7.00	3.00	1.00	1,323
2011	-1		7.00	9.00	7.00	3.00	1.00	1,323
2012	31	g	5.00	9.00	7.00	5.00	1.00	1,575
2014	16	p	7.00	9.00	7.00	5.00	1.00	2,205
2017	-1		7.00	9.00	7.00	5.00	1.00	2,205
2018	8	p	7.00	9.00	7.00	3.00	1.00	1,323
2019	24	p	7.00	9.00	7.00	5.00	1.00	2,205
2021	13	p	9.00	9.00	5.00	3.00	3.00	3,645
2023	12	g	9.00	9.00	7.00	1.00	1.00	567
2025	2	p	9.00	5.00	5.00	3.00	1.00	675
2026	22	p	9.00	9.00	7.00	5.00	1.00	2,835
2030	12	g	9.00	9.00	7.00	5.00	1.00	2,835
2032	-1		9.00	9.00	7.00	7.00	1.00	3,969
2033	12	p	9.00	9.00	7.00	5.00	1.00	2,835
2108	1	p	9.00	7.00	7.00	5.00	1.00	2,205
2111	5	p	9.00	1.00	7.00	3.00	1.00	189
2113	4	p	7.00	3.00	7.00	3.00	7.00	3,087
2211	5	g	9.00	7.00	5.00	1.00	1.00	315
2214	5	p	7.00	7.00	5.00	5.00	1.00	1,225
2216	13	p	7.00	9.00	5.00	5.00	1.00	1,575
2217	0	p	9.00	7.00	5.00	5.00	1.00	1,575
2218	11	p	9.00	9.00	5.00	3.00	1.00	1,215
2219	3	g	7.00	9.00	5.00	5.00	1.00	1,575
2220	-1		7.00	9.00	5.00	3.00	1.00	945
2310	4	p	9.00	9.00	5.00	5.00	1.00	2,025
2314	6	p	9.00	9.00	5.00	3.00	1.00	1,215
2316	6	p	7.00	9.00	5.00	3.00	1.00	945
2317	2	g	9.00	1.00	5.00	5.00	3.00	675
2323	3	p	7.00	3.00	5.00	5.00	1.00	525
2407	14	p	7.00	9.00	9.00	5.00	3.00	8,505
2409	-1		9.00	9.00	7.00	3.00	3.00	5,103
2410	2	p	9.00	7.00	7.00	5.00	3.00	6,615
2510	-1		7.00	9.00	5.00	3.00	1.00	945
2609	-1		7.00	9.00	7.00	3.00	3.00	3,969
2613	2	p	7.00	5.00	7.00	5.00	1.00	1,225
2615	3	p	7.00	7.00	7.00	1.00	3.00	1,029
2747	-1		7.00	9.00	7.00	3.00	1.00	1,323
2764	12	p	7.00	9.00	7.00	3.00	1.00	1,323
2766	1	g	7.00	9.00	7.00	3.00	1.00	1,323
2767	14	p	7.00	9.00	7.00	3.00	1.00	1,323
2768	12	p	9.00	7.00	7.00	3.00	1.00	1,323
2769	8	p	7.00	5.00	9.00	3.00	1.00	945
2770	2	p	9.00	5.00	7.00	5.00	1.00	1,575
2772	3	p	9.00	9.00	7.00	3.00	1.00	1,701
2773	4	p	9.00	9.00	7.00	3.00	1.00	1,701
2775	2	p	9.00	7.00	9.00	5.00	1.00	2,835
2776	3	p	7.00	5.00	7.00	3.00	1.00	735
2779	3	p	7.00	5.00	7.00	5.00	1.00	1,225
2780	7	g	7.00	9.00	7.00	5.00	1.00	2,205
2782	-1		7.00	9.00	9.00	5.00	1.00	2,835
2832	3	g	7.00	9.00	9.00	3.00	1.00	1,701
2833	10	g	7.00	7.00	7.00	3.00	3.00	3,087
2834	14	p	9.00	9.00	9.00	3.00	1.00	2,187
2841	4	p	7.00	9.00	7.00	5.00	1.00	2,205

Table I.1 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor F	Factor G	ESL
2842	2	p	7.00	9.00	9.00	5.00	1.00	2,835
2909	3	p	7.00	7.00	3.00	5.00	1.00	735
2910	7	g	7.00	7.00	3.00	5.00	3.00	2,205
2912	-1		7.00	9.00	3.00	7.00	3.00	3,969
2914	4	g	7.00	7.00	5.00	5.00	3.00	3,675
3024	11	p	9.00	9.00	5.00	3.00	1.00	1,215
3027	5	g	9.00	5.00	5.00	5.00	1.00	1,125
3029	8	p	7.00	7.00	5.00	3.00	1.00	735
3032	-1		7.00	9.00	5.00	7.00	1.00	2,205
3033	-1		9.00	9.00	5.00	7.00	1.00	2,835
3034	-1		7.00	9.00	5.00	5.00	1.00	1,575
3106	-1		5.00	9.00	9.00	7.00	1.00	2,835
3203	12	p	5.00	9.00	7.00	3.00	3.00	2,835
3208	2	g	9.00	5.00	7.00	5.00	1.00	1,575
3210	-1		3.00	9.00	7.00	9.00	1.00	1,701
3403	3	p	9.00	7.00	7.00	5.00	5.00	11,025
3408	-1		7.00	9.00	7.00	9.00	1.00	3,969
3487	5	p	7.00	9.00	7.00	5.00	5.00	11,025
3488	1	p	7.00	5.00	7.00	3.00	3.00	2,205
3514	-1		5.00	9.00	5.00	7.00	1.00	1,575
3515	10	g	3.00	7.00	3.00	5.00	1.00	315
3516	1	p	7.00	7.00	5.00	5.00	1.00	1,225
3517	-1		5.00	9.00	5.00	5.00	1.00	1,125
3627	-1		7.00	9.00	5.00	7.00	1.00	2,205
3641	14	p	7.00	9.00	5.00	5.00	1.00	1,575
3646	-1		7.00	9.00	5.00	7.00	1.00	2,205
3651	2	g	9.00	5.00	5.00	3.00	1.00	675
3652	2	p	7.00	7.00	5.00	5.00	1.00	1,225
3654	2	p	7.00	7.00	5.00	5.00	3.00	3,675
3655	12	p	7.00	9.00	3.00	5.00	1.00	945
3825	5	p	9.00	7.00	7.00	5.00	1.00	2,205
3835	8	p	7.00	9.00	7.00	3.00	1.00	1,323
3864	11	p	9.00	9.00	7.00	5.00	1.00	2,835
3865	12	p	9.00	9.00	7.00	1.00	1.00	567
3866	2	g	9.00	5.00	7.00	1.00	3.00	945
3867	23	p	9.00	9.00	7.00	5.00	1.00	2,835
3868	8	p	9.00	7.00	5.00	3.00	1.00	945
3872	6	p	5.00	7.00	7.00	5.00	1.00	1,225
3874	10	g	9.00	9.00	7.00	3.00	1.00	1,701
3875	-1		7.00	9.00	7.00	5.00	1.00	2,205
3882	-1		7.00	9.00	7.00	5.00	1.00	2,205
3911	-1		5.00	9.00	5.00	5.00	1.00	1,125
3913	5	p	7.00	7.00	5.00	5.00	3.00	3,675
3914	2	g	7.00	9.00	3.00	3.00	1.00	567
3915	-1		7.00	9.00	5.00	3.00	3.00	2,835
4025	-1		3.00	9.00	7.00	7.00	1.00	1,323
4026	-1		1.00	9.00	7.00	9.00	1.00	567
4149	3	p	7.00	5.00	7.00	7.00	1.00	1,715
4152	19	p	5.00	9.00	7.00	3.00	3.00	2,835
4158	12	p	9.00	9.00	7.00	5.00	1.00	2,835
4159	21	p	7.00	9.00	7.00	3.00	1.00	1,323
4162	18	p	9.00	9.00	7.00	5.00	3.00	8,505
4166	-1		7.00	9.00	5.00	5.00	5.00	7,875
4169	2	p	7.00	5.00	7.00	5.00	5.00	6,125
4171	2	g	9.00	7.00	7.00	5.00	5.00	11,025
4172	-1		7.00	9.00	7.00	3.00	5.00	6,615
4173	-1		9.00	9.00	7.00	7.00	5.00	19,845
4178	3	p	7.00	7.00	7.00	7.00	1.00	2,401
4279	-1		7.00	9.00	7.00	9.00	1.00	3,969
4286	4	p	9.00	9.00	7.00	7.00	3.00	11,907
4287	3	p	9.00	9.00	7.00	5.00	3.00	8,505
4413	2	p	1.00	7.00	7.00	9.00	1.00	441

Table I.1 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor F	Factor G	ESL
4416	18	p	5.00	9.00	7.00	7.00	1.00	2,205
4417	8	g	5.00	9.00	7.00	9.00	1.00	2,835
4418	-1		1.00	9.00	7.00	7.00	1.00	441
4635	-1		7.00	9.00	5.00	5.00	1.00	1,575
4643	-1		7.00	7.00	5.00	5.00	1.00	1,225
4645	-1		9.00	9.00	7.00	7.00	1.00	3,969
4650	4	p	7.00	7.00	5.00	7.00	1.00	1,715
4654	-1		7.00	9.00	5.00	9.00	1.00	2,835
4724	14	p	5.00	9.00	7.00	7.00	1.00	2,205
4732	2	p	5.00	9.00	7.00	5.00	1.00	1,575
4735	-1		3.00	9.00	7.00	3.00	1.00	567
4738	-1		1.00	7.00	7.00	7.00	1.00	343
4739	-1		1.00	9.00	7.00	5.00	1.00	315
4801	2	p	9.00	3.00	5.00	5.00	1.00	675
4802	3	p	9.00	3.00	5.00	5.00	1.00	675
4803	9	g	9.00	9.00	7.00	5.00	3.00	8,505
4921	5	p	7.00	7.00	7.00	7.00	1.00	2,401
4925	-1		7.00	9.00	7.00	5.00	1.00	2,205
4933	-1		9.00	7.00	9.00	5.00	1.00	2,835
4940	1	g	9.00	7.00	7.00	5.00	1.00	2,205
6155	9	p	9.00	3.00	7.00	7.00	5.00	6,615
6159	3	p	9.00	9.00	7.00	3.00	1.00	1,701
6160	2	p	9.00	5.00	7.00	7.00	3.00	6,615
6161	-1		9.00	9.00	7.00	5.00	1.00	2,835
6168	3	p	7.00	5.00	7.00	7.00	5.00	8,575
6172	9	p	7.00	7.00	7.00	9.00	5.00	15,435
6173	4	g	7.00	9.00	7.00	7.00	1.00	3,087
6174	4	g	7.00	7.00	7.00	5.00	5.00	8,575
6176	4	g	7.00	9.00	7.00	9.00	5.00	19,845
6220	33	g	7.00	9.00	7.00	5.00	5.00	11,025
6225	20	p	7.00	9.00	7.00	5.00	3.00	6,615
6313	9	p	9.00	9.00	1.00	1.00	1.00	81
6321	1	p	7.00	3.00	1.00	5.00	7.00	735
6322	-1		7.00	9.00	1.00	3.00	3.00	567
6335	5	g	7.00	7.00	3.00	5.00	1.00	735
6339	13	p	7.00	9.00	1.00	3.00	3.00	567
6341	5	p	5.00	7.00	1.00	1.00	3.00	105
6343	4	p	5.00	9.00	1.00	1.00	3.00	135
6350	7	p	7.00	7.00	1.00	5.00	7.00	1,715
6351	2	p	5.00	7.00	3.00	3.00	1.00	315
6363	5	p	7.00	7.00	3.00	5.00	1.00	735
6364	11	g	7.00	7.00	1.00	5.00	3.00	735
6367	6	g	5.00	9.00	1.00	5.00	1.00	225
6369	9	p	5.00	9.00	3.00	3.00	1.00	405
6371	-1		7.00	7.00	1.00	5.00	5.00	1,225
6372	2	g	7.00	9.00	1.00	3.00	5.00	945
6373	13	p	7.00	9.00	1.00	5.00	1.00	315
6374	-1		7.00	9.00	3.00	5.00	1.00	945
6375	20	p	7.00	9.00	1.00	5.00	1.00	315
6376	8	p	7.00	9.00	1.00	1.00	3.00	189
6377	14	g	9.00	9.00	3.00	3.00	1.00	729
6378	-1		5.00	9.00	1.00	5.00	5.00	1,125
6379	0	p	5.00	7.00	1.00	5.00	7.00	1,225
6380	-1		7.00	9.00	1.00	7.00	1.00	441
6517	8	p	7.00	9.00	3.00	5.00	3.00	2,835
6538	11	p	7.00	7.00	3.00	3.00	1.00	441
6555	5	g	7.00	9.00	3.00	5.00	1.00	945
6556	6	p	5.00	9.00	3.00	3.00	1.00	405
6559	1	p	7.00	5.00	3.00	5.00	3.00	1,575
6561	3	p	5.00	7.00	3.00	5.00	3.00	1,575
6563	1	p	7.00	7.00	3.00	3.00	1.00	441
6567	6	p	7.00	7.00	3.00	1.00	1.00	147

Table I.1 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor F	Factor G	ESL
6570	3	g	5.00	7.00	3.00	1.00	1.00	105
6574	8	p	7.00	9.00	3.00	3.00	1.00	567
6577	28	p	7.00	9.00	1.00	3.00	3.00	567
6578	9	g	7.00	9.00	3.00	3.00	3.00	1,701
6580	13	p	7.00	9.00	3.00	7.00	1.00	1,323
6581	13	p	7.00	9.00	3.00	5.00	1.00	945
6585	2	p	7.00	5.00	3.00	3.00	5.00	1,575
6587	7	p	7.00	7.00	3.00	5.00	3.00	2,205
6588	3	p	7.00	9.00	3.00	5.00	1.00	945
6589	2	p	9.00	9.00	3.00	5.00	3.00	3,645
6806	-1		7.00	9.00	3.00	9.00	1.00	1,701
6807	12	p	7.00	9.00	3.00	5.00	1.00	945
6814	2	p	7.00	5.00	3.00	5.00	5.00	2,625
6816	-1		7.00	9.00	3.00	5.00	7.00	6,615
6817	-1		7.00	9.00	3.00	1.00	7.00	1,323
6819	-1		7.00	9.00	3.00	5.00	1.00	945
6820	-1		7.00	9.00	3.00	5.00	1.00	945
6918	-1		7.00	9.00	5.00	7.00	1.00	2,205
6951	-1		7.00	9.00	1.00	7.00	1.00	441
6954	2	g	7.00	7.00	7.00	5.00	1.00	1,715
6959	-1		7.00	9.00	3.00	9.00	1.00	1,701
8413	-1		7.00	9.00	5.00	7.00	1.00	2,205
8418	4	p	7.00	7.00	3.00	5.00	5.00	3,675
8419	1	p	7.00	9.00	3.00	5.00	1.00	945
8429	2	p	7.00	5.00	5.00	7.00	1.00	1,225
8431	-1		7.00	9.00	7.00	5.00	1.00	2,205
8437	-1		7.00	5.00	3.00	7.00	1.00	735
8438	-1		7.00	9.00	3.00	5.00	5.00	4,725
8439	-1		7.00	7.00	3.00	5.00	1.00	735
8444	-1		7.00	9.00	1.00	5.00	9.00	2,835
8446	-1		7.00	9.00	3.00	5.00	1.00	945
8447	-1		7.00	9.00	1.00	7.00	1.00	441
8454	-1		7.00	9.00	3.00	5.00	1.00	945
8469	1	p	7.00	3.00	5.00	7.00	7.00	5,145
8518	-1		7.00	9.00	3.00	5.00	1.00	945
8519	-1		7.00	9.00	1.00	7.00	1.00	441
8520	-1		5.00	9.00	3.00	5.00	1.00	675
8521	-1		7.00	9.00	3.00	7.00	7.00	9,261
8523	-1		3.00	9.00	3.00	7.00	1.00	567
8527	-1		7.00	9.00	3.00	9.00	1.00	1,701
8531	4	p	7.00	9.00	3.00	5.00	1.00	945
8537	8	p	7.00	7.00	3.00	5.00	3.00	2,205
8539	-1		7.00	9.00	9.00	7.00	1.00	3,969
8540	1	p	7.00	5.00	3.00	5.00	3.00	1,575
8545	-1		7.00	9.00	1.00	9.00	1.00	567
8550	1	g	7.00	7.00	5.00	7.00	1.00	1,715
8561	-1		1.00	9.00	7.00	5.00	1.00	315
8563	-1		1.00	9.00	7.00	9.00	1.00	567
8577	-1		7.00	9.00	5.00	7.00	1.00	2,205
8583	-1		1.00	9.00	7.00	9.00	1.00	567
8598	-1		7.00	9.00	7.00	5.00	1.00	2,205
8913	2	p	7.00	7.00	5.00	5.00	1.00	1,225
8916	1	g	9.00	7.00	5.00	7.00	1.00	2,205
8918	-1		7.00	9.00	7.00	5.00	1.00	2,205
8919	-1		7.00	9.00	5.00	7.00	3.00	6,615
8922	10	p	7.00	9.00	5.00	3.00	3.00	2,835
8924	7	p	7.00	7.00	5.00	5.00	1.00	1,225
8926	-1		7.00	9.00	1.00	5.00	1.00	315
8929	5	p	7.00	7.00	1.00	5.00	3.00	735
8931	12	p	7.00	9.00	7.00	5.00	3.00	6,615
8941	-1		5.00	9.00	7.00	7.00	1.00	2,205
8951	-1		7.00	9.00	3.00	7.00	3.00	3,969

Table I.1 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor F	Factor G	ESL
8955	-1		7.00	9.00	5.00	7.00	1.00	2,205
8964	-1		3.00	9.00	7.00	7.00	1.00	1,323
8966	-1		1.00	9.00	7.00	9.00	1.00	567
8976	-1		7.00	9.00	3.00	7.00	1.00	1,323
8984	-1		7.00	9.00	5.00	1.00	1.00	315
8994	7	p	7.00	9.00	5.00	3.00	1.00	945
8996	-1		7.00	9.00	7.00	9.00	1.00	3,969
8998	-1		5.00	9.00	7.00	7.00	1.00	2,205
Note: -1 represent no leaks								

Table I.2 ESL Derived from Single Value Factor Class and ISO Suggested Coding

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor F	Factor G	ESL
164	5	g	1.05	1.00	1.00	0.90	0.90	0.851
170	-1		1.05	1.10	0.95	1.00	0.90	0.988
172	13	p	1.05	1.10	1.00	0.95	0.90	0.988
201	-1		1.05	1.10	0.90	1.00	0.95	0.988
374	12	p	1.05	1.10	0.95	1.00	0.90	0.988
375	9	p	1.05	1.05	0.95	0.95	0.95	0.945
376	-1		1.05	1.10	0.95	1.00	0.90	0.988
378	-1		1.05	1.10	0.95	1.00	0.90	0.988
379	6	g	1.05	1.10	0.95	1.00	0.90	0.988
380	-1		1.05	1.10	0.95	1.00	0.90	0.988
513	3	p	1.05	1.05	0.95	1.00	1.00	1.047
516	-1		1.05	1.10	0.90	1.00	1.00	1.040
518	4	p	1.05	1.05	0.95	1.00	0.90	0.943
735	1	p	1.05	0.90	1.00	1.00	0.90	0.851
740	27	g	1.05	1.10	1.00	1.00	0.90	1.040
742	2	g	1.10	1.00	1.00	1.00	0.90	0.990
743	1	p	1.05	1.00	1.00	1.05	1.05	1.158
744	10	p	1.05	1.05	1.00	1.00	0.90	0.992
745	6	p	1.05	1.10	1.00	1.00	0.95	1.097
805	23	g	1.10	1.10	1.00	0.95	0.90	1.035
808	4	p	1.05	1.05	0.95	0.95	0.95	0.945
809	12	g	1.05	1.10	1.00	1.00	0.90	1.040
810	-1		1.05	1.10	1.00	1.00	0.95	1.097
812	11	p	1.05	1.10	1.00	1.00	0.90	1.040
816	2	p	1.05	1.05	0.95	1.00	0.95	0.995
817	-1		1.05	1.10	0.95	1.00	0.90	0.988
888	14	p	1.05	1.10	1.00	1.00	0.90	1.040
963	-1		1.10	1.10	1.00	1.00	1.05	1.271
965	-1		1.05	1.10	1.00	1.05	0.95	1.152
984	13	p	1.10	1.10	1.00	1.00	0.95	1.150
1126	1	g	1.10	1.00	1.00	1.00	0.90	0.990
1129	1	p	1.05	1.10	1.00	1.00	0.90	1.040
1130	13	p	1.05	1.10	1.00	1.00	0.90	1.040
1262	26	g	1.05	1.10	1.05	1.05	1.00	1.273
1282	14	p	1.05	1.10	1.05	1.05	0.95	1.210
1405	4	g	1.05	1.05	1.00	1.00	0.90	0.992
1406	2	p	1.05	1.10	1.00	1.00	0.90	1.040
1407	5	p	1.05	1.05	0.95	1.00	0.95	0.995
1409	6	p	1.05	1.10	1.00	1.00	0.90	1.040
1410	3	g	1.05	1.05	1.00	0.95	0.90	0.943
1538	2	p	1.00	1.05	1.05	1.05	1.00	1.158
1540	11	p	0.95	1.10	1.05	1.00	1.00	1.097
1544	-1		0.95	1.10	1.05	1.00	0.90	0.988
1608	2	p	1.10	1.10	1.00	1.05	0.95	1.207
1754	19	p	1.05	1.10	1.00	0.95	0.90	0.988
1764	-1		1.05	1.10	1.00	0.95	0.90	0.988
1770	-1		1.05	1.10	0.95	1.05	0.90	1.037
1809	1	p	0.95	1.10	1.05	1.05	0.90	1.037
1810	-1		0.90	1.10	1.05	1.10	0.90	1.029
1943	-1		1.05	1.10	1.05	1.00	0.90	1.091
1948	2	p	1.05	1.05	1.05	1.05	0.90	1.094
1955	12	p	1.05	1.10	1.05	0.95	0.90	1.037
1956	3	p	1.05	1.10	1.05	1.00	0.90	1.091
1961	25	g	1.05	1.10	1.05	0.95	0.90	1.037
1967	1	p	1.10	1.05	1.05	1.00	0.90	1.091
1976	-1		1.10	1.10	1.05	0.95	0.90	1.086
1978	11	p	1.10	1.10	1.05	1.00	0.90	1.143
1979	3	p	1.10	1.05	1.00	0.95	0.90	0.988
1980	3	p	1.05	1.05	1.05	1.00	0.90	1.042
1982	-1		1.05	1.10	1.05	1.00	0.90	1.091
1983	12	p	1.10	1.10	1.05	1.00	0.90	1.143
1987	10	p	1.10	1.05	1.05	1.00	0.90	1.091

Table I.2 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor F	Factor G	ESL
1989	15	p	1.05	1.10	1.05	0.95	0.90	1.037
2011	-1		1.05	1.10	1.05	0.95	0.90	1.037
2012	31	g	1.00	1.10	1.05	1.00	0.90	1.040
2014	16	p	1.05	1.10	1.05	1.00	0.90	1.091
2017	-1		1.05	1.10	1.05	1.00	0.90	1.091
2018	8	p	1.05	1.10	1.05	0.95	0.90	1.037
2019	24	p	1.05	1.10	1.05	1.00	0.90	1.091
2021	13	p	1.10	1.10	1.00	0.95	0.95	1.092
2023	12	g	1.10	1.10	1.05	0.90	0.90	1.029
2025	2	p	1.10	1.00	1.00	0.95	0.90	0.941
2026	22	p	1.10	1.10	1.05	1.00	0.90	1.143
2030	12	g	1.10	1.10	1.05	1.00	0.90	1.143
2032	-1		1.10	1.10	1.05	1.05	0.90	1.201
2033	12	p	1.10	1.10	1.05	1.00	0.90	1.143
2108	1	p	1.10	1.05	1.05	1.00	0.90	1.091
2111	5	p	1.10	0.90	1.05	0.95	0.90	0.889
2113	4	p	1.05	0.95	1.05	0.95	1.05	1.045
2211	5	g	1.10	1.05	1.00	0.90	0.90	0.936
2214	5	p	1.05	1.05	1.00	1.00	0.90	0.992
2216	13	p	1.05	1.10	1.00	1.00	0.90	1.040
2217	0	p	1.10	1.05	1.00	1.00	0.90	1.040
2218	11	p	1.10	1.10	1.00	0.95	0.90	1.035
2219	3	g	1.05	1.10	1.00	1.00	0.90	1.040
2220	-1		1.05	1.10	1.00	0.95	0.90	0.988
2310	4	p	1.10	1.10	1.00	1.00	0.90	1.089
2314	6	p	1.10	1.10	1.00	0.95	0.90	1.035
2316	6	p	1.05	1.10	1.00	0.95	0.90	0.988
2317	2	g	1.10	0.90	1.00	1.00	0.95	0.941
2323	3	p	1.05	0.95	1.00	1.00	0.90	0.898
2407	14	p	1.05	1.10	1.10	1.00	0.95	1.207
2409	-1		1.10	1.10	1.05	0.95	0.95	1.147
2410	2	p	1.10	1.05	1.05	1.00	0.95	1.152
2510	-1		1.05	1.10	1.00	0.95	0.90	0.988
2609	-1		1.05	1.10	1.05	0.95	0.95	1.095
2613	2	p	1.05	1.00	1.05	1.00	0.90	0.992
2615	3	p	1.05	1.05	1.05	0.90	0.95	0.990
2747	-1		1.05	1.10	1.05	0.95	0.90	1.037
2764	12	p	1.05	1.10	1.05	0.95	0.90	1.037
2766	1	g	1.05	1.10	1.05	0.95	0.90	1.037
2767	14	p	1.05	1.10	1.05	0.95	0.90	1.037
2768	12	p	1.10	1.05	1.05	0.95	0.90	1.037
2769	8	p	1.05	1.00	1.10	0.95	0.90	0.988
2770	2	p	1.10	1.00	1.05	1.00	0.90	1.040
2772	3	p	1.10	1.10	1.05	0.95	0.90	1.086
2773	4	p	1.10	1.10	1.05	0.95	0.90	1.086
2775	2	p	1.10	1.05	1.10	1.00	0.90	1.143
2776	3	p	1.05	1.00	1.05	0.95	0.90	0.943
2779	3	p	1.05	1.00	1.05	1.00	0.90	0.992
2780	7	g	1.05	1.10	1.05	1.00	0.90	1.091
2782	-1		1.05	1.10	1.10	1.00	0.90	1.143
2832	3	g	1.05	1.10	1.10	0.95	0.90	1.086
2833	10	g	1.05	1.05	1.05	0.95	0.95	1.045
2834	14	p	1.10	1.10	1.10	0.95	0.90	1.138
2841	4	p	1.05	1.10	1.05	1.00	0.90	1.091
2842	2	p	1.05	1.10	1.10	1.00	0.90	1.143
2909	3	p	1.05	1.05	0.95	1.00	0.90	0.943
2910	7	g	1.05	1.05	0.95	1.00	0.95	0.995
2912	-1		1.05	1.10	0.95	1.05	0.95	1.095
2914	4	g	1.05	1.05	1.00	1.00	0.95	1.047
3024	11	p	1.10	1.10	1.00	0.95	0.90	1.035
3027	5	g	1.10	1.00	1.00	1.00	0.90	0.990
3029	8	p	1.05	1.05	1.00	0.95	0.90	0.943

Table I.2 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor F	Factor G	ESL
3032	-1		1.05	1.10	1.00	1.05	0.90	1.091
3033	-1		1.10	1.10	1.00	1.05	0.90	1.143
3034	-1		1.05	1.10	1.00	1.00	0.90	1.040
3106	-1		1.00	1.10	1.10	1.05	0.90	1.143
3203	12	p	1.00	1.10	1.05	0.95	0.95	1.042
3208	2	g	1.10	1.00	1.05	1.00	0.90	1.040
3210	-1		0.95	1.10	1.05	1.10	0.90	1.086
3403	3	p	1.10	1.05	1.05	1.00	1.00	1.213
3408	-1		1.05	1.10	1.05	1.10	0.90	1.201
3487	5	p	1.05	1.10	1.05	1.00	1.00	1.213
3488	1	p	1.05	1.00	1.05	0.95	0.95	0.995
3514	-1		1.00	1.10	1.00	1.05	0.90	1.040
3515	10	g	0.95	1.05	0.95	1.00	0.90	0.853
3516	1	p	1.05	1.05	1.00	1.00	0.90	0.992
3517	-1		1.00	1.10	1.00	1.00	0.90	0.990
3627	-1		1.05	1.10	1.00	1.05	0.90	1.091
3641	14	p	1.05	1.10	1.00	1.00	0.90	1.040
3646	-1		1.05	1.10	1.00	1.05	0.90	1.091
3651	2	g	1.10	1.00	1.00	0.95	0.90	0.941
3652	2	p	1.05	1.05	1.00	1.00	0.90	0.992
3654	2	p	1.05	1.05	1.00	1.00	0.95	1.047
3655	12	p	1.05	1.10	0.95	1.00	0.90	0.988
3825	5	p	1.10	1.05	1.05	1.00	0.90	1.091
3835	8	p	1.05	1.10	1.05	0.95	0.90	1.037
3864	11	p	1.10	1.10	1.05	1.00	0.90	1.143
3865	12	p	1.10	1.10	1.05	0.90	0.90	1.029
3866	2	g	1.10	1.00	1.05	0.90	0.95	0.988
3867	23	p	1.10	1.10	1.05	1.00	0.90	1.143
3868	8	p	1.10	1.05	1.00	0.95	0.90	0.988
3872	6	p	1.00	1.05	1.05	1.00	0.90	0.992
3874	10	g	1.10	1.10	1.05	0.95	0.90	1.086
3875	-1		1.05	1.10	1.05	1.00	0.90	1.091
3882	-1		1.05	1.10	1.05	1.00	0.90	1.091
3911	-1		1.00	1.10	1.00	1.00	0.90	0.990
3913	5	p	1.05	1.05	1.00	1.00	0.95	1.047
3914	2	g	1.05	1.10	0.95	0.95	0.90	0.938
3915	-1		1.05	1.10	1.00	0.95	0.95	1.042
4025	-1		0.95	1.10	1.05	1.05	0.90	1.037
4026	-1		0.90	1.10	1.05	1.10	0.90	1.029
4149	3	p	1.05	1.00	1.05	1.05	0.90	1.042
4152	19	p	1.00	1.10	1.05	0.95	0.95	1.042
4158	12	p	1.10	1.10	1.05	1.00	0.90	1.143
4159	21	p	1.05	1.10	1.05	0.95	0.90	1.037
4162	18	p	1.10	1.10	1.05	1.00	0.95	1.207
4166	-1		1.05	1.10	1.00	1.00	1.00	1.155
4169	2	p	1.05	1.00	1.05	1.00	1.00	1.103
4171	2	g	1.10	1.05	1.05	1.00	1.00	1.213
4172	-1		1.05	1.10	1.05	0.95	1.00	1.152
4173	-1		1.10	1.10	1.05	1.05	1.00	1.334
4178	3	p	1.05	1.05	1.05	1.05	0.90	1.094
4279	-1		1.05	1.10	1.05	1.10	0.90	1.201
4286	4	p	1.10	1.10	1.05	1.05	0.95	1.267
4287	3	p	1.10	1.10	1.05	1.00	0.95	1.207
4413	2	p	0.90	1.05	1.05	1.10	0.90	0.982
4416	18	p	1.00	1.10	1.05	1.05	0.90	1.091
4417	8	g	1.00	1.10	1.05	1.10	0.90	1.143
4418	-1		0.90	1.10	1.05	1.05	0.90	0.982
4635	-1		1.05	1.10	1.00	1.00	0.90	1.040
4643	-1		1.05	1.05	1.00	1.00	0.90	0.992
4645	-1		1.10	1.10	1.05	1.05	0.90	1.201
4650	4	p	1.05	1.05	1.00	1.05	0.90	1.042
4654	-1		1.05	1.10	1.00	1.10	0.90	1.143

Table I.2 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor F	Factor G	ESL
4724	14	p	1.00	1.10	1.05	1.05	0.90	1.091
4732	2	p	1.00	1.10	1.05	1.00	0.90	1.040
4735	-1		0.95	1.10	1.05	0.95	0.90	0.938
4738	-1		0.90	1.05	1.05	1.05	0.90	0.938
4739	-1		0.90	1.10	1.05	1.00	0.90	0.936
4801	2	p	1.10	0.95	1.00	1.00	0.90	0.941
4802	3	p	1.10	0.95	1.00	1.00	0.90	0.941
4803	9	g	1.10	1.10	1.05	1.00	0.95	1.207
4921	5	p	1.05	1.05	1.05	1.05	0.90	1.094
4925	-1		1.05	1.10	1.05	1.00	0.90	1.091
4933	-1		1.10	1.05	1.10	1.00	0.90	1.143
4940	1	g	1.10	1.05	1.05	1.00	0.90	1.091
6155	9	p	1.10	0.95	1.05	1.05	1.00	1.152
6159	3	p	1.10	1.10	1.05	0.95	0.90	1.086
6160	2	p	1.10	1.00	1.05	1.05	0.95	1.152
6161	-1		1.10	1.10	1.05	1.00	0.90	1.143
6168	3	p	1.05	1.00	1.05	1.05	1.00	1.158
6172	9	p	1.05	1.05	1.05	1.10	1.00	1.273
6173	4	g	1.05	1.10	1.05	1.05	0.90	1.146
6174	4	g	1.05	1.05	1.05	1.00	1.00	1.158
6176	4	g	1.05	1.10	1.05	1.10	1.00	1.334
6220	33	g	1.05	1.10	1.05	1.00	1.00	1.213
6225	20	p	1.05	1.10	1.05	1.00	0.95	1.152
6313	9	p	1.10	1.10	0.90	0.90	0.90	0.882
6321	1	p	1.05	0.95	0.90	1.00	1.05	0.943
6322	-1		1.05	1.10	0.90	0.95	0.95	0.938
6335	5	g	1.05	1.05	0.95	1.00	0.90	0.943
6339	13	p	1.05	1.10	0.90	0.95	0.95	0.938
6341	5	p	1.00	1.05	0.90	0.90	0.95	0.808
6343	4	p	1.00	1.10	0.90	0.90	0.95	0.846
6350	7	p	1.05	1.05	0.90	1.00	1.05	1.042
6351	2	p	1.00	1.05	0.95	0.95	0.90	0.853
6363	5	p	1.05	1.05	0.95	1.00	0.90	0.943
6364	11	g	1.05	1.05	0.90	1.00	0.95	0.943
6367	6	g	1.00	1.10	0.90	1.00	0.90	0.891
6369	9	p	1.00	1.10	0.95	0.95	0.90	0.893
6371	-1		1.05	1.05	0.90	1.00	1.00	0.992
6372	2	g	1.05	1.10	0.90	0.95	1.00	0.988
6373	13	p	1.05	1.10	0.90	1.00	0.90	0.936
6374	-1		1.05	1.10	0.95	1.00	0.90	0.988
6375	20	p	1.05	1.10	0.90	1.00	0.90	0.936
6376	8	p	1.05	1.10	0.90	0.90	0.95	0.889
6377	14	g	1.10	1.10	0.95	0.95	0.90	0.983
6378	-1		1.00	1.10	0.90	1.00	1.00	0.990
6379	0	p	1.00	1.05	0.90	1.00	1.05	0.992
6380	-1		1.05	1.10	0.90	1.05	0.90	0.982
6517	8	p	1.05	1.10	0.95	1.00	0.95	1.042
6538	11	p	1.05	1.05	0.95	0.95	0.90	0.896
6555	5	g	1.05	1.10	0.95	1.00	0.90	0.988
6556	6	p	1.00	1.10	0.95	0.95	0.90	0.893
6559	1	p	1.05	1.00	0.95	1.00	0.95	0.948
6561	3	p	1.00	1.05	0.95	1.00	0.95	0.948
6563	1	p	1.05	1.05	0.95	0.95	0.90	0.896
6567	6	p	1.05	1.05	0.95	0.90	0.90	0.848
6570	3	g	1.00	1.05	0.95	0.90	0.90	0.808
6574	8	p	1.05	1.10	0.95	0.95	0.90	0.938
6577	28	p	1.05	1.10	0.90	0.95	0.95	0.938
6578	9	g	1.05	1.10	0.95	0.95	0.95	0.990
6580	13	p	1.05	1.10	0.95	1.05	0.90	1.037
6581	13	p	1.05	1.10	0.95	1.00	0.90	0.988
6585	2	p	1.05	1.00	0.95	0.95	1.00	0.948
6587	7	p	1.05	1.05	0.95	1.00	0.95	0.995

Table I.2 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor F	Factor G	ESL
6588	3	p	1.05	1.10	0.95	1.00	0.90	0.988
6589	2	p	1.10	1.10	0.95	1.00	0.95	1.092
6806	-1		1.05	1.10	0.95	1.10	0.90	1.086
6807	12	p	1.05	1.10	0.95	1.00	0.90	0.988
6814	2	p	1.05	1.00	0.95	1.00	1.00	0.998
6816	-1		1.05	1.10	0.95	1.00	1.05	1.152
6817	-1		1.05	1.10	0.95	0.90	1.05	1.037
6819	-1		1.05	1.10	0.95	1.00	0.90	0.988
6820	-1		1.05	1.10	0.95	1.00	0.90	0.988
6918	-1		1.05	1.10	1.00	1.05	0.90	1.091
6951	-1		1.05	1.10	0.90	1.05	0.90	0.982
6954	2	g	1.05	1.05	1.05	1.00	0.90	1.042
6959	-1		1.05	1.10	0.95	1.10	0.90	1.086
8413	-1		1.05	1.10	1.00	1.05	0.90	1.091
8418	4	p	1.05	1.05	0.95	1.00	1.00	1.047
8419	1	p	1.05	1.10	0.95	1.00	0.90	0.988
8429	2	p	1.05	1.00	1.00	1.05	0.90	0.992
8431	-1		1.05	1.10	1.05	1.00	0.90	1.091
8437	-1		1.05	1.00	0.95	1.05	0.90	0.943
8438	-1		1.05	1.10	0.95	1.00	1.00	1.097
8439	-1		1.05	1.05	0.95	1.00	0.90	0.943
8444	-1		1.05	1.10	0.90	1.00	1.10	1.143
8446	-1		1.05	1.10	0.95	1.00	0.90	0.988
8447	-1		1.05	1.10	0.90	1.05	0.90	0.982
8454	-1		1.05	1.10	0.95	1.00	0.90	0.988
8469	1	p	1.05	0.95	1.00	1.05	1.05	1.100
8518	-1		1.05	1.10	0.95	1.00	0.90	0.988
8519	-1		1.05	1.10	0.90	1.05	0.90	0.982
8520	-1		1.00	1.10	0.95	1.00	0.90	0.941
8521	-1		1.05	1.10	0.95	1.05	1.05	1.210
8523	-1		0.95	1.10	0.95	1.05	0.90	0.938
8527	-1		1.05	1.10	0.95	1.10	0.90	1.086
8531	4	p	1.05	1.10	0.95	1.00	0.90	0.988
8537	8	p	1.05	1.05	0.95	1.00	0.95	0.995
8539	-1		1.05	1.10	1.10	1.05	0.90	1.201
8540	1	p	1.05	1.00	0.95	1.00	0.95	0.948
8545	-1		1.05	1.10	0.90	1.10	0.90	1.029
8550	1	g	1.05	1.05	1.00	1.05	0.90	1.042
8561	-1		0.90	1.10	1.05	1.00	0.90	0.936
8563	-1		0.90	1.10	1.05	1.10	0.90	1.029
8577	-1		1.05	1.10	1.00	1.05	0.90	1.091
8583	-1		0.90	1.10	1.05	1.10	0.90	1.029
8598	-1		1.05	1.10	1.05	1.00	0.90	1.091
8913	2	p	1.05	1.05	1.00	1.00	0.90	0.992
8916	1	g	1.10	1.05	1.00	1.05	0.90	1.091
8918	-1		1.05	1.10	1.05	1.00	0.90	1.091
8919	-1		1.05	1.10	1.00	1.05	0.95	1.152
8922	10	p	1.05	1.10	1.00	0.95	0.95	1.042
8924	7	p	1.05	1.05	1.00	1.00	0.90	0.992
8926	-1		1.05	1.10	0.90	1.00	0.90	0.936
8929	5	p	1.05	1.05	0.90	1.00	0.95	0.943
8931	12	p	1.05	1.10	1.05	1.00	0.95	1.152
8941	-1		1.00	1.10	1.05	1.05	0.90	1.091
8951	-1		1.05	1.10	0.95	1.05	0.95	1.095
8955	-1		1.05	1.10	1.00	1.05	0.90	1.091
8964	-1		0.95	1.10	1.05	1.05	0.90	1.037
8966	-1		0.90	1.10	1.05	1.10	0.90	1.029
8976	-1		1.05	1.10	0.95	1.05	0.90	1.037
8984	-1		1.05	1.10	1.00	0.90	0.90	0.936
8994	7	p	1.05	1.10	1.00	0.95	0.90	0.988
8996	-1		1.05	1.10	1.05	1.10	0.90	1.201
8998	-1		1.00	1.10	1.05	1.05	0.90	1.091

Table I.3 ESL Derived from Factor Classes (added sub-factors) and Arbitrary Coding

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
164	5	g	15.00	5.00	15.00	32.00	8.00	1.00	9,000	19,200
170	-1		17.00	9.00	13.00	26.00	14.00	1.00	27,846	55,692
172	13	p	15.00	9.00	15.00	32.00	12.00	1.00	24,300	51,840
201	-1		17.00	9.00	9.00	22.00	14.00	3.00	57,834	141,372
374	12	p	17.00	9.00	13.00	28.00	14.00	1.00	27,846	59,976
375	9	p	17.00	7.00	13.00	28.00	10.00	3.00	46,410	99,960
376	-1		17.00	9.00	13.00	28.00	14.00	1.00	27,846	59,976
378	-1		17.00	9.00	13.00	28.00	14.00	1.00	27,846	59,976
379	6	g	17.00	9.00	13.00	30.00	14.00	1.00	27,846	64,260
380	-1		17.00	9.00	13.00	26.00	14.00	1.00	27,846	55,692
513	3	p	17.00	7.00	13.00	30.00	12.00	5.00	92,820	214,200
516	-1		17.00	9.00	11.00	30.00	14.00	5.00	117,810	321,300
518	4	p	17.00	7.00	13.00	26.00	14.00	1.00	21,658	43,316
735	1	p	17.00	1.00	15.00	34.00	6.00	1.00	1,530	3,468
740	27	g	17.00	9.00	15.00	34.00	14.00	1.00	32,130	72,828
742	2	g	19.00	5.00	15.00	32.00	8.00	1.00	11,400	24,320
743	1	p	17.00	5.00	15.00	32.00	12.00	7.00	107,100	228,480
744	10	p	17.00	7.00	15.00	32.00	14.00	1.00	24,990	53,312
745	6	p	17.00	9.00	15.00	30.00	14.00	3.00	96,390	192,780
805	23	g	19.00	9.00	15.00	32.00	12.00	1.00	30,780	65,664
808	4	p	17.00	7.00	13.00	28.00	10.00	3.00	46,410	99,960
809	12	g	17.00	9.00	15.00	32.00	12.00	1.00	27,540	58,752
810	-1		17.00	9.00	15.00	32.00	14.00	3.00	96,390	205,632
812	11	p	17.00	9.00	15.00	34.00	14.00	1.00	32,130	72,828
816	2	p	17.00	7.00	13.00	30.00	12.00	3.00	55,692	128,520
817	-1		17.00	9.00	13.00	28.00	14.00	1.00	27,846	59,976
888	14	p	17.00	9.00	15.00	32.00	14.00	1.00	32,130	68,544
963	-1		19.00	9.00	17.00	34.00	14.00	7.00	284,886	569,772
965	-1		17.00	9.00	17.00	34.00	16.00	3.00	124,848	249,696
984	13	p	19.00	9.00	17.00	38.00	10.00	3.00	87,210	194,940
1126	1	g	19.00	5.00	15.00	32.00	14.00	1.00	19,950	42,560
1129	1	p	17.00	9.00	15.00	32.00	14.00	1.00	32,130	68,544
1130	13	p	17.00	9.00	15.00	32.00	14.00	1.00	32,130	68,544
1262	26	g	17.00	9.00	21.00	38.00	16.00	5.00	257,040	465,120
1282	14	p	17.00	9.00	19.00	34.00	16.00	3.00	139,536	249,696
1405	4	g	17.00	7.00	15.00	32.00	14.00	1.00	24,990	53,312
1406	2	p	17.00	9.00	15.00	32.00	14.00	1.00	32,130	68,544
1407	5	p	17.00	7.00	13.00	32.00	12.00	3.00	55,692	137,088
1409	6	p	17.00	9.00	17.00	36.00	14.00	1.00	36,414	77,112
1410	3	g	17.00	7.00	17.00	34.00	10.00	1.00	20,230	40,460
1538	2	p	15.00	7.00	19.00	24.00	14.00	5.00	139,650	176,400
1540	11	p	13.00	9.00	21.00	28.00	12.00	5.00	147,420	196,560
1544	-1		13.00	9.00	21.00	30.00	14.00	1.00	34,398	49,140
1608	2	p	19.00	9.00	19.00	36.00	16.00	3.00	155,952	295,488
1754	19	p	17.00	9.00	15.00	34.00	12.00	1.00	27,540	62,424
1764	-1		17.00	9.00	15.00	34.00	12.00	1.00	27,540	62,424
1770	-1		17.00	9.00	11.00	26.00	16.00	1.00	26,928	63,648
1809	1	p	13.00	9.00	21.00	40.00	14.00	1.00	34,398	65,520
1810	-1		11.00	9.00	23.00	40.00	18.00	1.00	40,986	71,280
1943	-1		17.00	9.00	21.00	40.00	14.00	1.00	44,982	85,680
1948	2	p	17.00	7.00	21.00	40.00	14.00	1.00	34,986	66,640
1955	12	p	15.00	9.00	21.00	38.00	12.00	1.00	34,020	61,560
1956	3	p	17.00	9.00	21.00	40.00	14.00	1.00	44,982	85,680
1961	25	g	17.00	9.00	21.00	38.00	12.00	1.00	38,556	69,768
1967	1	p	19.00	7.00	19.00	38.00	14.00	1.00	35,378	70,756
1976	-1		17.00	9.00	21.00	38.00	12.00	1.00	38,556	69,768
1978	11	p	19.00	9.00	21.00	40.00	14.00	1.00	50,274	95,760
1979	3	p	19.00	7.00	15.00	30.00	12.00	1.00	23,940	47,880
1980	3	p	17.00	7.00	21.00	38.00	14.00	1.00	34,986	63,308
1982	-1		17.00	9.00	21.00	38.00	14.00	1.00	44,982	81,396
1983	12	p	19.00	9.00	21.00	38.00	12.00	1.00	43,092	77,976
1987	10	p	19.00	7.00	21.00	42.00	12.00	1.00	33,516	67,032

Table I.3 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
1989	15	p	17.00	9.00	21.00	42.00	12.00	1.00	38,556	77,112
2011	-1		17.00	9.00	21.00	38.00	12.00	1.00	38,556	69,768
2012	31	g	11.00	9.00	21.00	38.00	14.00	1.00	29,106	52,668
2014	16	p	13.00	9.00	21.00	38.00	14.00	1.00	34,398	62,244
2017	-1		17.00	9.00	21.00	36.00	14.00	1.00	44,982	77,112
2018	8	p	17.00	9.00	21.00	40.00	12.00	1.00	38,556	73,440
2019	24	p	17.00	9.00	21.00	40.00	14.00	1.00	44,982	85,680
2021	13	p	19.00	9.00	17.00	38.00	12.00	3.00	104,652	233,928
2023	12	g	19.00	9.00	21.00	40.00	8.00	1.00	28,728	54,720
2025	2	p	19.00	5.00	17.00	36.00	10.00	1.00	16,150	34,200
2026	22	p	19.00	9.00	21.00	40.00	14.00	1.00	50,274	95,760
2030	12	g	19.00	9.00	21.00	40.00	14.00	1.00	50,274	95,760
2032	-1		19.00	9.00	21.00	40.00	16.00	1.00	57,456	109,440
2033	12	p	19.00	9.00	21.00	42.00	12.00	1.00	43,092	86,184
2108	1	p	19.00	7.00	21.00	38.00	12.00	1.00	33,516	60,648
2111	5	p	19.00	1.00	21.00	38.00	6.00	1.00	2,394	4,332
2113	4	p	17.00	3.00	21.00	38.00	6.00	7.00	44,982	81,396
2211	5	g	19.00	7.00	17.00	34.00	10.00	1.00	22,610	45,220
2214	5	p	17.00	7.00	17.00	36.00	14.00	1.00	28,322	59,976
2216	13	p	17.00	9.00	17.00	36.00	14.00	1.00	36,414	77,112
2217	0	p	19.00	7.00	17.00	34.00	12.00	1.00	27,132	54,264
2218	11	p	19.00	9.00	17.00	36.00	12.00	1.00	34,884	73,872
2219	3	g	17.00	9.00	17.00	30.00	14.00	1.00	36,414	64,260
2220	-1		17.00	9.00	17.00	34.00	12.00	1.00	31,212	62,424
2310	4	p	19.00	9.00	17.00	36.00	14.00	1.00	40,698	86,184
2314	6	p	19.00	9.00	15.00	32.00	10.00	1.00	25,650	54,720
2316	6	p	17.00	9.00	17.00	34.00	12.00	1.00	31,212	62,424
2317	2	g	19.00	1.00	17.00	32.00	6.00	3.00	5,814	10,944
2323	3	p	17.00	3.00	19.00	38.00	8.00	1.00	7,752	15,504
2407	14	p	17.00	9.00	17.00	36.00	12.00	3.00	93,636	198,288
2409	-1		19.00	9.00	19.00	36.00	12.00	3.00	116,964	221,616
2410	2	p	19.00	7.00	19.00	36.00	12.00	3.00	90,972	172,368
2510	-1		17.00	9.00	19.00	36.00	12.00	1.00	34,884	66,096
2609	-1		17.00	9.00	19.00	36.00	12.00	3.00	104,652	198,288
2613	2	p	17.00	5.00	19.00	32.00	12.00	1.00	19,380	32,640
2615	3	p	17.00	7.00	19.00	36.00	8.00	3.00	54,264	102,816
2747	-1		17.00	9.00	21.00	40.00	12.00	1.00	38,556	73,440
2764	12	p	15.00	9.00	21.00	40.00	12.00	1.00	34,020	64,800
2766	1	g	17.00	9.00	21.00	40.00	12.00	1.00	38,556	73,440
2767	14	p	15.00	9.00	21.00	40.00	8.00	1.00	22,680	43,200
2768	12	p	17.00	7.00	21.00	42.00	12.00	1.00	29,988	59,976
2769	8	p	15.00	5.00	25.00	40.00	10.00	1.00	18,750	30,000
2770	2	p	19.00	5.00	21.00	38.00	12.00	1.00	23,940	43,320
2772	3	p	19.00	9.00	21.00	40.00	10.00	1.00	35,910	68,400
2773	4	p	19.00	9.00	21.00	40.00	10.00	1.00	35,910	68,400
2775	2	p	19.00	7.00	23.00	42.00	12.00	1.00	36,708	67,032
2776	3	p	17.00	5.00	21.00	42.00	10.00	1.00	17,850	35,700
2779	3	p	17.00	5.00	21.00	36.00	10.00	1.00	17,850	30,600
2780	7	g	17.00	9.00	21.00	42.00	14.00	1.00	44,982	89,964
2782	-1		17.00	9.00	25.00	40.00	14.00	1.00	53,550	85,680
2832	3	g	17.00	9.00	23.00	40.00	12.00	1.00	42,228	73,440
2833	10	g	17.00	7.00	21.00	42.00	12.00	3.00	89,964	179,928
2834	14	p	19.00	9.00	23.00	40.00	12.00	1.00	47,196	82,080
2841	4	p	17.00	9.00	21.00	38.00	14.00	1.00	44,982	81,396
2842	2	p	17.00	9.00	23.00	42.00	14.00	1.00	49,266	89,964
2909	3	p	17.00	7.00	13.00	32.00	14.00	1.00	21,658	53,312
2910	7	g	17.00	7.00	11.00	22.00	12.00	3.00	47,124	94,248
2912	-1		17.00	9.00	13.00	30.00	16.00	3.00	95,472	220,320
2914	4	g	17.00	7.00	15.00	32.00	12.00	3.00	64,260	137,088
3024	11	p	19.00	9.00	17.00	36.00	12.00	1.00	34,884	73,872
3027	5	g	19.00	5.00	17.00	34.00	10.00	1.00	16,150	32,300
3029	8	p	17.00	7.00	17.00	36.00	12.00	1.00	24,276	51,408

Table I.3 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
3032	-1		17.00	9.00	17.00	36.00	16.00	1.00	41,616	88,128
3033	-1		19.00	9.00	15.00	32.00	16.00	1.00	41,040	87,552
3034	-1		17.00	9.00	17.00	36.00	14.00	1.00	36,414	77,112
3106	-1		15.00	9.00	25.00	38.00	16.00	1.00	54,000	82,080
3203	12	p	15.00	9.00	19.00	38.00	10.00	3.00	76,950	153,900
3208	2	g	19.00	5.00	21.00	40.00	12.00	1.00	23,940	45,600
3210	-1		13.00	9.00	21.00	36.00	18.00	1.00	44,226	75,816
3403	3	p	19.00	7.00	21.00	36.00	10.00	5.00	139,650	239,400
3408	-1		17.00	9.00	21.00	32.00	18.00	1.00	57,834	88,128
3487	5	p	17.00	9.00	21.00	38.00	14.00	5.00	224,910	406,980
3488	1	p	17.00	5.00	21.00	32.00	8.00	3.00	42,840	65,280
3514	-1		15.00	9.00	15.00	28.00	16.00	1.00	32,400	60,480
3515	10	g	13.00	7.00	13.00	28.00	14.00	1.00	16,562	35,672
3516	1	p	17.00	7.00	17.00	24.00	14.00	1.00	28,322	39,984
3517	-1		15.00	9.00	15.00	24.00	14.00	1.00	28,350	45,360
3627	-1		17.00	9.00	17.00	34.00	16.00	1.00	41,616	83,232
3641	14	p	15.00	9.00	17.00	36.00	14.00	1.00	32,130	68,040
3646	-1		17.00	9.00	17.00	34.00	16.00	1.00	41,616	83,232
3651	2	g	17.00	5.00	17.00	34.00	10.00	1.00	14,450	28,900
3652	2	p	17.00	7.00	17.00	32.00	14.00	1.00	28,322	53,312
3654	2	p	17.00	7.00	17.00	32.00	12.00	3.00	72,828	137,088
3655	12	p	17.00	9.00	13.00	26.00	14.00	1.00	27,846	55,692
3825	5	p	19.00	7.00	21.00	38.00	14.00	1.00	39,102	70,756
3835	8	p	13.00	9.00	21.00	40.00	12.00	1.00	29,484	56,160
3864	11	p	17.00	9.00	21.00	42.00	14.00	1.00	44,982	89,964
3865	12	p	17.00	9.00	21.00	38.00	8.00	1.00	25,704	46,512
3866	2	g	19.00	5.00	21.00	42.00	4.00	3.00	23,940	47,880
3867	23	p	17.00	9.00	21.00	42.00	14.00	1.00	44,982	89,964
3868	8	p	19.00	7.00	19.00	38.00	12.00	1.00	30,324	60,648
3872	6	p	15.00	7.00	21.00	38.00	12.00	1.00	26,460	47,880
3874	10	g	19.00	9.00	21.00	40.00	10.00	1.00	35,910	68,400
3875	-1		17.00	9.00	21.00	40.00	14.00	1.00	44,982	85,680
3882	-1		17.00	9.00	21.00	40.00	14.00	1.00	44,982	85,680
3911	-1		15.00	9.00	15.00	32.00	12.00	1.00	24,300	51,840
3913	5	p	17.00	7.00	17.00	34.00	12.00	3.00	72,828	145,656
3914	2	g	17.00	9.00	13.00	28.00	12.00	1.00	23,868	51,408
3915	-1		17.00	9.00	17.00	36.00	12.00	3.00	93,636	198,288
4025	-1		13.00	9.00	21.00	40.00	16.00	1.00	39,312	74,880
4026	-1		11.00	9.00	23.00	40.00	18.00	1.00	40,986	71,280
4149	3	p	17.00	5.00	21.00	40.00	12.00	1.00	21,420	40,800
4152	19	p	13.00	9.00	21.00	40.00	10.00	3.00	73,710	140,400
4158	12	p	19.00	9.00	21.00	40.00	14.00	1.00	50,274	95,760
4159	21	p	15.00	9.00	21.00	40.00	12.00	1.00	34,020	64,800
4162	18	p	19.00	9.00	21.00	40.00	12.00	3.00	129,276	246,240
4166	-1		17.00	9.00	19.00	36.00	14.00	5.00	203,490	385,560
4169	2	p	17.00	5.00	21.00	38.00	10.00	5.00	89,250	161,500
4171	2	g	19.00	7.00	21.00	36.00	12.00	5.00	167,580	287,280
4172	-1		17.00	9.00	21.00	42.00	12.00	5.00	192,780	385,560
4173	-1		19.00	9.00	21.00	38.00	16.00	5.00	287,280	519,840
4178	3	p	17.00	7.00	21.00	40.00	14.00	1.00	34,986	66,640
4279	-1		17.00	9.00	19.00	36.00	18.00	1.00	52,326	99,144
4286	4	p	19.00	9.00	19.00	34.00	16.00	3.00	155,952	279,072
4287	3	p	19.00	9.00	19.00	34.00	14.00	3.00	136,458	244,188
4413	2	p	11.00	7.00	21.00	36.00	16.00	1.00	25,872	44,352
4416	18	p	15.00	9.00	21.00	38.00	16.00	1.00	45,360	82,080
4417	8	g	15.00	9.00	21.00	38.00	18.00	1.00	51,030	92,340
4418	-1		11.00	9.00	19.00	34.00	16.00	1.00	30,096	53,856
4635	-1		17.00	9.00	17.00	34.00	14.00	1.00	36,414	72,828
4643	-1		17.00	7.00	17.00	34.00	12.00	1.00	24,276	48,552
4645	-1		19.00	9.00	19.00	34.00	16.00	1.00	51,984	93,024
4650	4	p	17.00	7.00	17.00	32.00	16.00	1.00	32,368	60,928
4654	-1		17.00	9.00	17.00	36.00	18.00	1.00	46,818	99,144

Table I.3 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
4724	14	p	15.00	9.00	21.00	38.00	16.00	1.00	45,360	82,080
4732	2	p	15.00	9.00	23.00	38.00	14.00	1.00	43,470	71,820
4735	-1		13.00	9.00	21.00	38.00	12.00	1.00	29,484	53,352
4738	-1		11.00	7.00	23.00	36.00	14.00	1.00	24,794	38,808
4739	-1		11.00	9.00	21.00	38.00	14.00	1.00	29,106	52,668
4801	2	p	19.00	3.00	19.00	34.00	10.00	1.00	10,830	19,380
4802	3	p	19.00	3.00	19.00	34.00	10.00	1.00	10,830	19,380
4803	9	g	19.00	9.00	21.00	38.00	14.00	3.00	150,822	272,916
4921	5	p	17.00	7.00	21.00	42.00	14.00	1.00	34,986	69,972
4925	-1		17.00	9.00	21.00	40.00	14.00	1.00	44,982	85,680
4933	-1		19.00	7.00	23.00	40.00	14.00	1.00	42,826	74,480
4940	1	g	19.00	7.00	21.00	42.00	12.00	1.00	33,516	67,032
6155	9	p	19.00	3.00	21.00	40.00	12.00	5.00	71,820	136,800
6159	3	p	19.00	9.00	21.00	42.00	12.00	1.00	43,092	86,184
6160	2	p	19.00	5.00	21.00	38.00	14.00	3.00	83,790	151,620
6161	-1		19.00	9.00	21.00	38.00	14.00	1.00	50,274	90,972
6168	3	p	17.00	5.00	21.00	42.00	10.00	5.00	89,250	178,500
6172	9	p	17.00	7.00	21.00	40.00	16.00	5.00	199,920	380,800
6173	4	g	17.00	9.00	21.00	42.00	16.00	1.00	51,408	102,816
6174	4	g	17.00	7.00	21.00	38.00	10.00	5.00	124,950	226,100
6176	4	g	17.00	9.00	21.00	38.00	18.00	5.00	289,170	523,260
6220	33	g	15.00	9.00	19.00	34.00	14.00	5.00	179,550	321,300
6225	20	p	17.00	9.00	21.00	36.00	14.00	3.00	134,946	231,336
6313	9	p	19.00	9.00	11.00	22.00	10.00	1.00	18,810	37,620
6321	1	p	17.00	3.00	11.00	26.00	8.00	7.00	31,416	74,256
6322	-1		17.00	9.00	9.00	20.00	12.00	3.00	49,572	110,160
6335	5	g	15.00	7.00	11.00	24.00	12.00	1.00	13,860	30,240
6339	13	p	17.00	9.00	9.00	22.00	10.00	3.00	41,310	100,980
6341	5	p	15.00	7.00	9.00	24.00	10.00	3.00	28,350	75,600
6343	4	p	15.00	9.00	9.00	20.00	10.00	3.00	36,450	81,000
6350	7	p	17.00	7.00	9.00	26.00	12.00	7.00	89,964	259,896
6351	2	p	15.00	7.00	13.00	24.00	12.00	1.00	16,380	30,240
6363	5	p	17.00	7.00	11.00	24.00	14.00	1.00	18,326	39,984
6364	11	g	17.00	7.00	11.00	24.00	14.00	3.00	54,978	119,952
6367	6	g	15.00	9.00	9.00	24.00	12.00	1.00	14,580	38,880
6369	9	p	15.00	9.00	13.00	26.00	12.00	1.00	21,060	42,120
6371	-1		17.00	7.00	9.00	24.00	12.00	5.00	64,260	171,360
6372	2	g	17.00	9.00	9.00	20.00	12.00	5.00	82,620	183,600
6373	13	p	17.00	9.00	9.00	20.00	14.00	1.00	19,278	42,840
6374	-1		17.00	9.00	11.00	24.00	14.00	1.00	23,562	51,408
6375	20	p	17.00	9.00	9.00	26.00	12.00	1.00	16,524	47,736
6376	8	p	17.00	9.00	9.00	24.00	8.00	3.00	33,048	88,128
6377	14	g	19.00	9.00	13.00	28.00	10.00	1.00	22,230	47,880
6378	-1		15.00	9.00	9.00	20.00	14.00	5.00	85,050	189,000
6379	0	p	15.00	7.00	9.00	22.00	12.00	7.00	79,380	194,040
6380	-1		17.00	9.00	11.00	26.00	16.00	1.00	26,928	63,648
6517	8	p	17.00	9.00	15.00	32.00	14.00	3.00	96,390	205,632
6538	11	p	17.00	7.00	13.00	30.00	10.00	1.00	15,470	35,700
6555	5	g	17.00	9.00	13.00	30.00	12.00	1.00	23,868	55,080
6556	6	p	13.00	9.00	13.00	32.00	12.00	1.00	18,252	44,928
6559	1	p	17.00	5.00	13.00	28.00	12.00	3.00	39,780	85,680
6561	3	p	15.00	7.00	13.00	30.00	12.00	3.00	49,140	113,400
6563	1	p	17.00	7.00	13.00	30.00	10.00	1.00	15,470	35,700
6567	6	p	17.00	7.00	13.00	26.00	6.00	1.00	9,282	18,564
6570	3	g	15.00	7.00	13.00	30.00	8.00	1.00	10,920	25,200
6574	8	p	17.00	9.00	15.00	32.00	12.00	1.00	27,540	58,752
6577	28	p	17.00	9.00	11.00	30.00	12.00	3.00	60,588	165,240
6578	9	g	15.00	9.00	13.00	30.00	12.00	3.00	63,180	145,800
6580	13	p	17.00	9.00	13.00	32.00	16.00	1.00	31,824	78,336
6581	13	p	17.00	9.00	13.00	30.00	12.00	1.00	23,868	55,080
6585	2	p	17.00	5.00	13.00	32.00	8.00	5.00	44,200	108,800
6587	7	p	17.00	7.00	15.00	34.00	12.00	3.00	64,260	145,656

Table I.3 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
6588	3	p	17.00	9.00	13.00	28.00	14.00	1.00	27,846	59,976
6589	2	p	19.00	9.00	13.00	32.00	14.00	3.00	93,366	229,824
6806	-1		17.00	9.00	13.00	28.00	18.00	1.00	35,802	77,112
6807	12	p	17.00	9.00	15.00	32.00	14.00	1.00	32,130	68,544
6814	2	p	17.00	5.00	13.00	28.00	10.00	5.00	55,250	119,000
6816	-1		17.00	9.00	13.00	30.00	14.00	7.00	194,922	449,820
6817	-1		17.00	9.00	13.00	32.00	10.00	7.00	139,230	342,720
6819	-1		17.00	9.00	13.00	26.00	14.00	1.00	27,846	55,692
6820	-1		17.00	9.00	15.00	32.00	14.00	1.00	32,130	68,544
6918	-1		17.00	9.00	15.00	32.00	16.00	1.00	36,720	78,336
6951	-1		17.00	9.00	11.00	26.00	16.00	1.00	26,928	63,648
6954	2	g	17.00	7.00	21.00	40.00	12.00	1.00	29,988	57,120
6959	-1		17.00	9.00	11.00	24.00	18.00	1.00	30,294	66,096
8413	-1		17.00	9.00	15.00	32.00	16.00	1.00	36,720	78,336
8418	4	p	17.00	7.00	13.00	28.00	12.00	5.00	92,820	199,920
8419	1	p	17.00	9.00	13.00	26.00	14.00	1.00	27,846	55,692
8429	2	p	17.00	5.00	19.00	36.00	12.00	1.00	19,380	36,720
8431	-1		17.00	9.00	21.00	40.00	14.00	1.00	44,982	85,680
8437	-1		17.00	5.00	13.00	30.00	12.00	1.00	13,260	30,600
8438	-1		17.00	9.00	13.00	28.00	14.00	5.00	139,230	299,880
8439	-1		17.00	7.00	13.00	28.00	12.00	1.00	18,564	39,984
8444	-1		17.00	9.00	9.00	22.00	14.00	9.00	173,502	424,116
8446	-1		17.00	9.00	13.00	30.00	14.00	1.00	27,846	64,260
8447	-1		17.00	9.00	9.00	24.00	16.00	1.00	22,032	58,752
8454	-1		17.00	9.00	13.00	28.00	14.00	1.00	27,846	59,976
8469	1	p	17.00	3.00	15.00	34.00	10.00	7.00	53,550	121,380
8518	-1		17.00	9.00	13.00	30.00	14.00	1.00	27,846	64,260
8519	-1		17.00	9.00	11.00	30.00	16.00	1.00	26,928	73,440
8520	-1		15.00	9.00	13.00	26.00	14.00	1.00	24,570	49,140
8521	-1		17.00	9.00	13.00	32.00	16.00	7.00	222,768	548,352
8523	-1		13.00	9.00	13.00	28.00	16.00	1.00	24,336	52,416
8527	-1		17.00	9.00	15.00	28.00	18.00	1.00	41,310	77,112
8531	4	p	17.00	9.00	13.00	28.00	14.00	1.00	27,846	59,976
8537	8	p	17.00	7.00	13.00	30.00	12.00	3.00	55,692	128,520
8539	-1		17.00	9.00	17.00	32.00	16.00	1.00	41,616	78,336
8540	1	p	17.00	5.00	13.00	30.00	8.00	3.00	26,520	61,200
8545	-1		17.00	9.00	9.00	22.00	18.00	1.00	24,786	60,588
8550	1	g	17.00	7.00	19.00	40.00	14.00	1.00	31,654	66,640
8561	-1		11.00	9.00	17.00	38.00	14.00	1.00	23,562	52,668
8563	-1		11.00	9.00	17.00	36.00	18.00	1.00	30,294	64,152
8577	-1		17.00	9.00	15.00	34.00	16.00	1.00	36,720	83,232
8583	-1		11.00	9.00	21.00	38.00	18.00	1.00	37,422	67,716
8598	-1		17.00	9.00	21.00	38.00	14.00	1.00	44,982	81,396
8913	2	p	17.00	7.00	17.00	30.00	12.00	1.00	24,276	42,840
8916	1	g	19.00	7.00	15.00	30.00	14.00	1.00	27,930	55,860
8918	-1		17.00	9.00	21.00	36.00	14.00	1.00	44,982	77,112
8919	-1		17.00	9.00	15.00	32.00	16.00	3.00	110,160	235,008
8922	10	p	17.00	9.00	17.00	36.00	12.00	3.00	93,636	198,288
8924	7	p	17.00	7.00	15.00	32.00	12.00	1.00	21,420	45,696
8926	-1		17.00	9.00	9.00	26.00	14.00	1.00	19,278	55,692
8929	5	p	17.00	7.00	11.00	30.00	14.00	3.00	54,978	149,940
8931	12	p	17.00	9.00	21.00	36.00	14.00	3.00	134,946	231,336
8941	-1		15.00	9.00	21.00	38.00	16.00	1.00	45,360	82,080
8951	-1		17.00	9.00	13.00	30.00	16.00	3.00	95,472	220,320
8955	-1		17.00	9.00	19.00	36.00	16.00	1.00	46,512	88,128
8964	-1		13.00	9.00	19.00	34.00	16.00	1.00	35,568	63,648
8966	-1		11.00	9.00	23.00	38.00	18.00	1.00	40,986	67,716
8976	-1		17.00	9.00	13.00	30.00	16.00	1.00	31,824	73,440
8984	-1		17.00	9.00	17.00	34.00	10.00	1.00	26,010	52,020
8994	7	p	17.00	9.00	17.00	34.00	12.00	1.00	31,212	62,424
8996	-1		17.00	9.00	21.00	42.00	18.00	1.00	57,834	115,668
8998	-1		15.00	9.00	17.00	26.00	16.00	1.00	36,720	56,160

Table I.4 ESL Derived from Factor Classes (added sub-factors) and ISO Suggested Coding

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
164	5	g	3.00	1.00	3.00	6.05	1.95	0.90	15.795	31.853
170	-1		3.05	1.10	2.95	5.90	2.10	0.90	18.706	37.412
172	13	p	3.00	1.10	3.00	6.05	2.05	0.90	18.266	36.835
201	-1		3.05	1.10	2.85	5.80	2.10	0.95	19.076	38.821
374	12	p	3.05	1.10	2.95	5.95	2.10	0.90	18.706	37.729
375	9	p	3.05	1.05	2.95	5.95	2.00	0.95	17.950	36.204
376	-1		3.05	1.10	2.95	5.95	2.10	0.90	18.706	37.729
378	-1		3.05	1.10	2.95	5.95	2.10	0.90	18.706	37.729
379	6	g	3.05	1.10	2.95	6.00	2.10	0.90	18.706	38.046
380	-1		3.05	1.10	2.95	5.90	2.10	0.90	18.706	37.412
513	3	p	3.05	1.05	2.95	6.00	2.05	1.00	19.367	39.391
516	-1		3.05	1.10	2.90	6.00	2.10	1.00	20.432	42.273
518	4	p	3.05	1.05	2.95	5.90	2.10	0.90	17.856	35.711
735	1	p	3.05	0.90	3.00	6.10	1.90	0.90	14.082	28.633
740	27	g	3.05	1.10	3.00	6.10	2.10	0.90	19.023	38.680
742	2	g	3.10	1.00	3.00	6.05	1.95	0.90	16.322	32.915
743	1	p	3.05	1.00	3.00	6.05	2.05	1.05	19.695	39.719
744	10	p	3.05	1.05	3.00	6.05	2.10	0.90	18.158	36.619
745	6	p	3.05	1.10	3.00	6.00	2.10	0.95	20.080	40.159
805	23	g	3.10	1.10	3.00	6.05	2.05	0.90	18.874	38.063
808	4	p	3.05	1.05	2.95	5.95	2.00	0.95	17.950	36.204
809	12	g	3.05	1.10	3.00	6.05	2.05	0.90	18.570	37.449
810	-1		3.05	1.10	3.00	6.05	2.10	0.95	20.080	40.494
812	11	p	3.05	1.10	3.00	6.10	2.10	0.90	19.023	38.680
816	2	p	3.05	1.05	2.95	6.00	2.05	0.95	18.399	37.421
817	-1		3.05	1.10	2.95	5.95	2.10	0.90	18.706	37.729
888	14	p	3.05	1.10	3.00	6.05	2.10	0.90	19.023	38.363
963	-1		3.10	1.10	3.05	6.10	2.10	1.05	22.933	45.866
965	-1		3.05	1.10	3.05	6.10	2.15	0.95	20.900	41.801
984	13	p	3.10	1.10	3.05	6.20	2.00	0.95	19.761	40.170
1126	1	g	3.10	1.00	3.00	6.05	2.10	0.90	17.577	35.447
1129	1	p	3.05	1.10	3.00	6.05	2.10	0.90	19.023	38.363
1130	13	p	3.05	1.10	3.00	6.05	2.10	0.90	19.023	38.363
1262	26	g	3.05	1.10	3.15	6.20	2.15	1.00	22.722	44.722
1282	14	p	3.05	1.10	3.10	6.10	2.15	0.95	21.243	41.801
1405	4	g	3.05	1.05	3.00	6.05	2.10	0.90	18.158	36.619
1406	2	p	3.05	1.10	3.00	6.05	2.10	0.90	19.023	38.363
1407	5	p	3.05	1.05	2.95	6.05	2.05	0.95	18.399	37.733
1409	6	p	3.05	1.10	3.05	6.15	2.10	0.90	19.340	38.997
1410	3	g	3.05	1.05	3.05	6.10	2.00	0.90	17.582	35.163
1538	2	p	3.00	1.05	3.10	5.85	2.10	1.00	20.507	38.698
1540	11	p	2.95	1.10	3.15	5.95	2.05	1.00	20.955	39.581
1544	-1		2.95	1.10	3.15	6.00	2.10	0.90	19.319	36.798
1608	2	p	3.10	1.10	3.10	6.15	2.15	0.95	21.591	42.834
1754	19	p	3.05	1.10	3.00	6.10	2.05	0.90	18.570	37.759
1764	-1		3.05	1.10	3.00	6.10	2.05	0.90	18.570	37.759
1770	-1		3.05	1.10	2.90	5.90	2.15	0.90	18.827	38.302
1809	1	p	2.95	1.10	3.15	6.25	2.10	0.90	19.319	38.332
1810	-1		2.90	1.10	3.20	6.25	2.20	0.90	20.212	39.476
1943	-1		3.05	1.10	3.15	6.25	2.10	0.90	19.974	39.631
1948	2	p	3.05	1.05	3.15	6.25	2.10	0.90	19.066	37.830
1955	12	p	3.00	1.10	3.15	6.20	2.05	0.90	19.179	37.749
1956	3	p	3.05	1.10	3.15	6.25	2.10	0.90	19.974	39.631
1961	25	g	3.05	1.10	3.15	6.20	2.05	0.90	19.498	38.378
1967	1	p	3.10	1.05	3.10	6.20	2.10	0.90	19.071	38.142
1976	-1		3.05	1.10	3.15	6.20	2.05	0.90	19.498	38.378
1978	11	p	3.10	1.10	3.15	6.25	2.10	0.90	20.301	40.281
1979	3	p	3.10	1.05	3.00	6.00	2.05	0.90	18.016	36.033
1980	3	p	3.05	1.05	3.15	6.20	2.10	0.90	19.066	37.527
1982	-1		3.05	1.10	3.15	6.20	2.10	0.90	19.974	39.314
1983	12	p	3.10	1.10	3.15	6.20	2.05	0.90	19.818	39.007
1987	10	p	3.10	1.05	3.15	6.30	2.05	0.90	18.917	37.834

Table I.4 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
1989	15	p	3.05	1.10	3.15	6.30	2.05	0.90	19.498	38.997
2011	-1		3.05	1.10	3.15	6.20	2.05	0.90	19.498	38.378
2012	31	g	2.90	1.10	3.15	6.20	2.10	0.90	18.992	37.380
2014	16	p	2.95	1.10	3.15	6.20	2.10	0.90	19.319	38.025
2017	-1		3.05	1.10	3.15	6.15	2.10	0.90	19.974	38.997
2018	8	p	3.05	1.10	3.15	6.25	2.05	0.90	19.498	38.687
2019	24	p	3.05	1.10	3.15	6.25	2.10	0.90	19.974	39.631
2021	13	p	3.10	1.10	3.05	6.20	2.05	0.95	20.255	41.174
2023	12	g	3.10	1.10	3.15	6.25	1.95	0.90	18.851	37.403
2025	2	p	3.10	1.00	3.05	6.15	2.00	0.90	17.019	34.317
2026	22	p	3.10	1.10	3.15	6.25	2.10	0.90	20.301	40.281
2030	12	g	3.10	1.10	3.15	6.25	2.10	0.90	20.301	40.281
2032	-1		3.10	1.10	3.15	6.25	2.15	0.90	20.785	41.240
2033	12	p	3.10	1.10	3.15	6.30	2.05	0.90	19.818	39.636
2108	1	p	3.10	1.05	3.15	6.20	2.05	0.90	18.917	37.234
2111	5	p	3.10	0.90	3.15	6.20	1.90	0.90	15.028	29.580
2113	4	p	3.05	0.95	3.15	6.20	1.90	1.05	18.209	35.839
2211	5	g	3.10	1.05	3.05	6.10	2.00	0.90	17.870	35.740
2214	5	p	3.05	1.05	3.05	6.15	2.10	0.90	18.461	37.224
2216	13	p	3.05	1.10	3.05	6.15	2.10	0.90	19.340	38.997
2217	0	p	3.10	1.05	3.05	6.10	2.05	0.90	18.317	36.633
2218	11	p	3.10	1.10	3.05	6.15	2.05	0.90	19.189	38.692
2219	3	g	3.05	1.10	3.05	6.00	2.10	0.90	19.340	38.046
2220	-1		3.05	1.10	3.05	6.10	2.05	0.90	18.879	37.759
2310	4	p	3.10	1.10	3.05	6.15	2.10	0.90	19.657	39.636
2314	6	p	3.10	1.10	3.00	6.05	2.00	0.90	18.414	37.135
2316	6	p	3.05	1.10	3.05	6.10	2.05	0.90	18.879	37.759
2317	2	g	3.10	0.90	3.05	6.05	1.90	0.95	15.360	30.467
2323	3	p	3.05	0.95	3.10	6.20	1.95	0.90	15.764	31.528
2407	14	p	3.05	1.10	3.05	6.15	2.05	0.95	19.928	40.183
2409	-1		3.10	1.10	3.10	6.15	2.05	0.95	20.587	40.842
2410	2	p	3.10	1.05	3.10	6.15	2.05	0.95	19.651	38.986
2510	-1		3.05	1.10	3.10	6.15	2.05	0.90	19.189	38.068
2609	-1		3.05	1.10	3.10	6.15	2.05	0.95	20.255	40.183
2613	2	p	3.05	1.00	3.10	6.05	2.05	0.90	17.444	34.045
2615	3	p	3.05	1.05	3.10	6.15	1.95	0.95	18.391	36.486
2747	-1		3.05	1.10	3.15	6.25	2.05	0.90	19.498	38.687
2764	12	p	3.00	1.10	3.15	6.25	2.05	0.90	19.179	38.053
2766	1	g	3.05	1.10	3.15	6.25	2.05	0.90	19.498	38.687
2767	14	p	3.00	1.10	3.15	6.25	1.95	0.90	18.243	36.197
2768	12	p	3.05	1.05	3.15	6.30	2.05	0.90	18.612	37.224
2769	8	p	3.00	1.00	3.25	6.25	2.00	0.90	17.550	33.750
2770	2	p	3.10	1.00	3.15	6.20	2.05	0.90	18.016	35.461
2772	3	p	3.10	1.10	3.15	6.25	2.00	0.90	19.335	38.363
2773	4	p	3.10	1.10	3.15	6.25	2.00	0.90	19.335	38.363
2775	2	p	3.10	1.05	3.20	6.30	2.05	0.90	19.218	37.834
2776	3	p	3.05	1.00	3.15	6.30	2.00	0.90	17.294	34.587
2779	3	p	3.05	1.00	3.15	6.15	2.00	0.90	17.294	33.764
2780	7	g	3.05	1.10	3.15	6.30	2.10	0.90	19.974	39.948
2782	-1		3.05	1.10	3.25	6.25	2.10	0.90	20.608	39.631
2832	3	g	3.05	1.10	3.20	6.25	2.05	0.90	19.808	38.687
2833	10	g	3.05	1.05	3.15	6.30	2.05	0.95	19.646	39.292
2834	14	p	3.10	1.10	3.20	6.25	2.05	0.90	20.133	39.322
2841	4	p	3.05	1.10	3.15	6.20	2.10	0.90	19.974	39.314
2842	2	p	3.05	1.10	3.20	6.30	2.10	0.90	20.291	39.948
2909	3	p	3.05	1.05	2.95	6.05	2.10	0.90	17.856	36.619
2910	7	g	3.05	1.05	2.90	5.80	2.05	0.95	18.087	36.174
2912	-1		3.05	1.10	2.95	6.00	2.15	0.95	20.215	41.116
2914	4	g	3.05	1.05	3.00	6.05	2.05	0.95	18.711	37.733
3024	11	p	3.10	1.10	3.05	6.15	2.05	0.90	19.189	38.692
3027	5	g	3.10	1.00	3.05	6.10	2.00	0.90	17.019	34.038
3029	8	p	3.05	1.05	3.05	6.15	2.05	0.90	18.021	36.338

Table I.4 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
3032	-1		3.05	1.10	3.05	6.15	2.15	0.90	19.800	39.925
3033	-1		3.10	1.10	3.00	6.05	2.15	0.90	19.795	39.920
3034	-1		3.05	1.10	3.05	6.15	2.10	0.90	19.340	38.997
3106	-1		3.00	1.10	3.25	6.20	2.15	0.90	20.753	39.590
3203	12	p	3.00	1.10	3.10	6.20	2.00	0.95	19.437	38.874
3208	2	g	3.10	1.00	3.15	6.25	2.05	0.90	18.016	35.747
3210	-1		2.95	1.10	3.15	6.15	2.20	0.90	20.239	39.514
3403	3	p	3.10	1.05	3.15	6.15	2.00	1.00	20.507	40.037
3408	-1		3.05	1.10	3.15	6.05	2.20	0.90	20.925	40.190
3487	5	p	3.05	1.10	3.15	6.20	2.10	1.00	22.193	43.682
3488	1	p	3.05	1.00	3.15	6.05	1.95	0.95	17.798	34.183
3514	-1		3.00	1.10	3.00	5.95	2.15	0.90	19.157	37.994
3515	10	g	2.95	1.05	2.95	5.95	2.10	0.90	17.270	34.833
3516	1	p	3.05	1.05	3.05	5.85	2.10	0.90	18.461	35.408
3517	-1		3.00	1.10	3.00	5.85	2.10	0.90	18.711	36.486
3627	-1		3.05	1.10	3.05	6.10	2.15	0.90	19.800	39.601
3641	14	p	3.00	1.10	3.05	6.15	2.10	0.90	19.023	38.358
3646	-1		3.05	1.10	3.05	6.10	2.15	0.90	19.800	39.601
3651	2	g	3.05	1.00	3.05	6.10	2.00	0.90	16.745	33.489
3652	2	p	3.05	1.05	3.05	6.05	2.10	0.90	18.461	36.619
3654	2	p	3.05	1.05	3.05	6.05	2.05	0.95	19.022	37.733
3655	12	p	3.05	1.10	2.95	5.90	2.10	0.90	18.706	37.412
3825	5	p	3.10	1.05	3.15	6.20	2.10	0.90	19.379	38.142
3835	8	p	2.95	1.10	3.15	6.25	2.05	0.90	18.859	37.419
3864	11	p	3.05	1.10	3.15	6.30	2.10	0.90	19.974	39.948
3865	12	p	3.05	1.10	3.15	6.20	1.95	0.90	18.547	36.506
3866	2	g	3.10	1.00	3.15	6.30	1.85	0.95	17.162	34.324
3867	23	p	3.05	1.10	3.15	6.30	2.10	0.90	19.974	39.948
3868	8	p	3.10	1.05	3.10	6.20	2.05	0.90	18.617	37.234
3872	6	p	3.00	1.05	3.15	6.20	2.05	0.90	18.307	36.033
3874	10	g	3.10	1.10	3.15	6.25	2.00	0.90	19.335	38.363
3875	-1		3.05	1.10	3.15	6.25	2.10	0.90	19.974	39.631
3882	-1		3.05	1.10	3.15	6.25	2.10	0.90	19.974	39.631
3911	-1		3.00	1.10	3.00	6.05	2.05	0.90	18.266	36.835
3913	5	p	3.05	1.05	3.05	6.10	2.05	0.95	19.022	38.045
3914	2	g	3.05	1.10	2.95	5.95	2.05	0.90	18.260	36.830
3915	-1		3.05	1.10	3.05	6.15	2.05	0.95	19.928	40.183
4025	-1		2.95	1.10	3.15	6.25	2.15	0.90	19.779	39.244
4026	-1		2.90	1.10	3.20	6.25	2.20	0.90	20.212	39.476
4149	3	p	3.05	1.00	3.15	6.25	2.05	0.90	17.726	35.170
4152	19	p	2.95	1.10	3.15	6.25	2.00	0.95	19.421	38.534
4158	12	p	3.10	1.10	3.15	6.25	2.10	0.90	20.301	40.281
4159	21	p	3.00	1.10	3.15	6.25	2.05	0.90	19.179	38.053
4162	18	p	3.10	1.10	3.15	6.25	2.05	0.95	20.919	41.506
4166	-1		3.05	1.10	3.10	6.15	2.10	1.00	21.841	43.330
4169	2	p	3.05	1.00	3.15	6.20	2.00	1.00	19.215	37.820
4171	2	g	3.10	1.05	3.15	6.15	2.05	1.00	21.019	41.037
4172	-1		3.05	1.10	3.15	6.30	2.05	1.00	21.665	43.330
4173	-1		3.10	1.10	3.15	6.20	2.15	1.00	23.094	45.455
4178	3	p	3.05	1.05	3.15	6.25	2.10	0.90	19.066	37.830
4279	-1		3.05	1.10	3.10	6.15	2.20	0.90	20.593	40.854
4286	4	p	3.10	1.10	3.10	6.10	2.15	0.95	21.591	42.486
4287	3	p	3.10	1.10	3.10	6.10	2.10	0.95	21.089	41.498
4413	2	p	2.90	1.05	3.15	6.15	2.15	0.90	18.560	36.236
4416	18	p	3.00	1.10	3.15	6.20	2.15	0.90	20.114	39.590
4417	8	g	3.00	1.10	3.15	6.20	2.20	0.90	20.582	40.511
4418	-1		2.90	1.10	3.10	6.10	2.15	0.90	19.135	37.653
4635	-1		3.05	1.10	3.05	6.10	2.10	0.90	19.340	38.680
4643	-1		3.05	1.05	3.05	6.10	2.05	0.90	18.021	36.043
4645	-1		3.10	1.10	3.10	6.10	2.15	0.90	20.455	40.250
4650	4	p	3.05	1.05	3.05	6.05	2.15	0.90	18.900	37.491
4654	-1		3.05	1.10	3.05	6.15	2.20	0.90	20.261	40.854

Table I.4 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
4724	14	p	3.00	1.10	3.15	6.20	2.15	0.90	20.114	39.590
4732	2	p	3.00	1.10	3.20	6.20	2.10	0.90	19.958	38.669
4735	-1		2.95	1.10	3.15	6.20	2.05	0.90	18.859	37.120
4738	-1		2.90	1.05	3.20	6.15	2.10	0.90	18.416	35.394
4739	-1		2.90	1.10	3.15	6.20	2.10	0.90	18.992	37.380
4801	2	p	3.10	0.95	3.10	6.10	2.00	0.90	16.433	32.336
4802	3	p	3.10	0.95	3.10	6.10	2.00	0.90	16.433	32.336
4803	9	g	3.10	1.10	3.15	6.20	2.10	0.95	21.429	42.178
4921	5	p	3.05	1.05	3.15	6.30	2.10	0.90	19.066	38.132
4925	-1		3.05	1.10	3.15	6.25	2.10	0.90	19.974	39.631
4933	-1		3.10	1.05	3.20	6.25	2.10	0.90	19.686	38.450
4940	1	g	3.10	1.05	3.15	6.30	2.05	0.90	18.917	37.834
6155	9	p	3.10	0.95	3.15	6.25	2.05	1.00	19.017	37.733
6159	3	p	3.10	1.10	3.15	6.30	2.05	0.90	19.818	39.636
6160	2	p	3.10	1.00	3.15	6.20	2.10	0.95	19.481	38.344
6161	-1		3.10	1.10	3.15	6.20	2.10	0.90	20.301	39.958
6168	3	p	3.05	1.00	3.15	6.30	2.00	1.00	19.215	38.430
6172	9	p	3.05	1.05	3.15	6.25	2.15	1.00	21.689	43.034
6173	4	g	3.05	1.10	3.15	6.30	2.15	0.90	20.450	40.899
6174	4	g	3.05	1.05	3.15	6.20	2.00	1.00	20.176	39.711
6176	4	g	3.05	1.10	3.15	6.20	2.20	1.00	23.250	45.762
6220	33	g	3.00	1.10	3.10	6.10	2.10	1.00	21.483	42.273
6225	20	p	3.05	1.10	3.15	6.15	2.10	0.95	21.084	41.163
6313	9	p	3.10	1.10	2.90	5.80	2.00	0.90	17.800	35.600
6321	1	p	3.05	0.95	2.90	5.90	1.95	1.05	17.205	35.003
6322	-1		3.05	1.10	2.85	5.75	2.05	0.95	18.622	37.570
6335	5	g	3.00	1.05	2.90	5.85	2.05	0.90	16.854	33.999
6339	13	p	3.05	1.10	2.85	5.80	2.00	0.95	18.167	36.972
6341	5	p	3.00	1.05	2.85	5.85	2.00	0.95	17.057	35.012
6343	4	p	3.00	1.10	2.85	5.75	2.00	0.95	17.870	36.053
6350	7	p	3.05	1.05	2.85	5.90	2.05	1.05	19.646	40.671
6351	2	p	3.00	1.05	2.95	5.85	2.05	0.90	17.145	33.999
6363	5	p	3.05	1.05	2.90	5.85	2.10	0.90	17.553	35.408
6364	11	g	3.05	1.05	2.90	5.85	2.10	0.95	18.528	37.376
6367	6	g	3.00	1.10	2.85	5.85	2.05	0.90	17.352	35.618
6369	9	p	3.00	1.10	2.95	5.90	2.05	0.90	17.961	35.922
6371	-1		3.05	1.05	2.85	5.85	2.05	1.00	18.711	38.406
6372	2	g	3.05	1.10	2.85	5.75	2.05	1.00	19.602	39.547
6373	13	p	3.05	1.10	2.85	5.75	2.10	0.90	18.072	36.460
6374	-1		3.05	1.10	2.90	5.85	2.10	0.90	18.389	37.095
6375	20	p	3.05	1.10	2.85	5.90	2.05	0.90	17.641	36.521
6376	8	p	3.05	1.10	2.85	5.85	1.95	0.95	17.713	36.359
6377	14	g	3.10	1.10	2.95	5.95	2.00	0.90	18.107	36.521
6378	-1		3.00	1.10	2.85	5.75	2.10	1.00	19.751	39.848
6379	0	p	3.00	1.05	2.85	5.80	2.05	1.05	19.324	39.326
6380	-1		3.05	1.10	2.90	5.90	2.15	0.90	18.827	38.302
6517	8	p	3.05	1.10	3.00	6.05	2.10	0.95	20.080	40.494
6538	11	p	3.05	1.05	2.95	6.00	2.00	0.90	17.005	34.587
6555	5	g	3.05	1.10	2.95	6.00	2.05	0.90	18.260	37.140
6556	6	p	2.95	1.10	2.95	6.05	2.05	0.90	17.662	36.222
6559	1	p	3.05	1.00	2.95	5.95	2.05	0.95	17.523	35.342
6561	3	p	3.00	1.05	2.95	6.00	2.05	0.95	18.097	36.808
6563	1	p	3.05	1.05	2.95	6.00	2.00	0.90	17.005	34.587
6567	6	p	3.05	1.05	2.95	5.90	1.90	0.90	16.155	32.310
6570	3	g	3.00	1.05	2.95	6.00	1.95	0.90	16.308	33.170
6574	8	p	3.05	1.10	3.00	6.05	2.05	0.90	18.570	37.449
6577	28	p	3.05	1.10	2.90	6.00	2.05	0.95	18.948	39.203
6578	9	g	3.00	1.10	2.95	6.00	2.05	0.95	18.959	38.561
6580	13	p	3.05	1.10	2.95	6.05	2.15	0.90	19.151	39.276
6581	13	p	3.05	1.10	2.95	6.00	2.05	0.90	18.260	37.140
6585	2	p	3.05	1.00	2.95	6.05	1.95	1.00	17.545	35.982
6587	7	p	3.05	1.05	3.00	6.10	2.05	0.95	18.711	38.045

Table I.4 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
6588	3	p	3.05	1.10	2.95	5.95	2.10	0.90	18.706	37.729
6589	2	p	3.10	1.10	2.95	6.05	2.10	0.95	20.069	41.158
6806	-1		3.05	1.10	2.95	5.95	2.20	0.90	19.597	39.525
6807	12	p	3.05	1.10	3.00	6.05	2.10	0.90	19.023	38.363
6814	2	p	3.05	1.00	2.95	5.95	2.00	1.00	17.995	36.295
6816	-1		3.05	1.10	2.95	6.00	2.10	1.05	21.823	44.387
6817	-1		3.05	1.10	2.95	6.05	2.00	1.05	20.784	42.625
6819	-1		3.05	1.10	2.95	5.90	2.10	0.90	18.706	37.412
6820	-1		3.05	1.10	3.00	6.05	2.10	0.90	19.023	38.363
6918	-1		3.05	1.10	3.00	6.05	2.15	0.90	19.476	39.276
6951	-1		3.05	1.10	2.90	5.90	2.15	0.90	18.827	38.302
6954	2	g	3.05	1.05	3.15	6.25	2.05	0.90	18.612	36.929
6959	-1		3.05	1.10	2.90	5.85	2.20	0.90	19.264	38.861
8413	-1		3.05	1.10	3.00	6.05	2.15	0.90	19.476	39.276
8418	4	p	3.05	1.05	2.95	5.95	2.05	1.00	19.367	39.062
8419	1	p	3.05	1.10	2.95	5.90	2.10	0.90	18.706	37.412
8429	2	p	3.05	1.00	3.10	6.15	2.05	0.90	17.444	34.608
8431	-1		3.05	1.10	3.15	6.25	2.10	0.90	19.974	39.631
8437	-1		3.05	1.00	2.95	6.00	2.05	0.90	16.600	33.764
8438	-1		3.05	1.10	2.95	5.95	2.10	1.00	20.784	41.921
8439	-1		3.05	1.05	2.95	5.95	2.05	0.90	17.430	35.156
8444	-1		3.05	1.10	2.85	5.80	2.10	1.10	22.088	44.950
8446	-1		3.05	1.10	2.95	6.00	2.10	0.90	18.706	38.046
8447	-1		3.05	1.10	2.85	5.85	2.15	0.90	18.502	37.978
8454	-1		3.05	1.10	2.95	5.95	2.10	0.90	18.706	37.729
8469	1	p	3.05	0.95	3.00	6.10	2.00	1.05	18.254	37.117
8518	-1		3.05	1.10	2.95	6.00	2.10	0.90	18.706	38.046
8519	-1		3.05	1.10	2.90	6.00	2.15	0.90	18.827	38.952
8520	-1		3.00	1.10	2.95	5.90	2.10	0.90	18.399	36.798
8521	-1		3.05	1.10	2.95	6.05	2.15	1.05	22.343	45.822
8523	-1		2.95	1.10	2.95	5.95	2.15	0.90	18.523	37.360
8527	-1		3.05	1.10	3.00	5.95	2.20	0.90	19.929	39.525
8531	4	p	3.05	1.10	2.95	5.95	2.10	0.90	18.706	37.729
8537	8	p	3.05	1.05	2.95	6.00	2.05	0.95	18.399	37.421
8539	-1		3.05	1.10	3.05	6.05	2.15	0.90	19.800	39.276
8540	1	p	3.05	1.00	2.95	6.00	1.95	0.95	16.668	33.901
8545	-1		3.05	1.10	2.85	5.80	2.20	0.90	18.932	38.529
8550	1	g	3.05	1.05	3.10	6.25	2.10	0.90	18.763	37.830
8561	-1		2.90	1.10	3.05	6.20	2.10	0.90	18.389	37.380
8563	-1		2.90	1.10	3.05	6.15	2.20	0.90	19.264	38.845
8577	-1		3.05	1.10	3.00	6.10	2.15	0.90	19.476	39.601
8583	-1		2.90	1.10	3.15	6.20	2.20	0.90	19.896	39.160
8598	-1		3.05	1.10	3.15	6.20	2.10	0.90	19.974	39.314
8913	2	p	3.05	1.05	3.05	6.00	2.05	0.90	18.021	35.452
8916	1	g	3.10	1.05	3.00	6.00	2.10	0.90	18.456	36.912
8918	-1		3.05	1.10	3.15	6.15	2.10	0.90	19.974	38.997
8919	-1		3.05	1.10	3.00	6.05	2.15	0.95	20.558	41.458
8922	10	p	3.05	1.10	3.05	6.15	2.05	0.95	19.928	40.183
8924	7	p	3.05	1.05	3.00	6.05	2.05	0.90	17.726	35.747
8926	-1		3.05	1.10	2.85	5.90	2.10	0.90	18.072	37.412
8929	5	p	3.05	1.05	2.90	6.00	2.10	0.95	18.528	38.334
8931	12	p	3.05	1.10	3.15	6.15	2.10	0.95	21.084	41.163
8941	-1		3.00	1.10	3.15	6.20	2.15	0.90	20.114	39.590
8951	-1		3.05	1.10	2.95	6.00	2.15	0.95	20.215	41.116
8955	-1		3.05	1.10	3.10	6.15	2.15	0.90	20.125	39.925
8964	-1		2.95	1.10	3.10	6.10	2.15	0.90	19.465	38.302
8966	-1		2.90	1.10	3.20	6.20	2.20	0.90	20.212	39.160
8976	-1		3.05	1.10	2.95	6.00	2.15	0.90	19.151	38.952
8984	-1		3.05	1.10	3.05	6.10	2.00	0.90	18.419	36.838
8994	7	p	3.05	1.10	3.05	6.10	2.05	0.90	18.879	37.759
8996	-1		3.05	1.10	3.15	6.30	2.20	0.90	20.925	41.850
8998	-1		3.00	1.10	3.05	5.90	2.15	0.90	19.476	37.674

Table I.5 ESL Derived from Factor Classes (multiplied sub-factors) and Arbitrary Coding

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
164	5	g	105.00	5.00	125.00	16,875.00	7.00	1.00	459,375	62,015,625
170	-1		175.00	9.00	75.00	5,625.00	45.00	1.00	5,315,625	398,671,875
172	13	p	105.00	9.00	125.00	16,875.00	27.00	1.00	3,189,375	430,565,625
201	-1		175.00	9.00	15.00	1,125.00	45.00	3.00	3,189,375	239,203,125
374	12	p	175.00	9.00	75.00	7,875.00	45.00	1.00	5,315,625	558,140,625
375	9	p	175.00	7.00	75.00	7,875.00	21.00	3.00	5,788,125	607,753,125
376	-1		175.00	9.00	75.00	7,875.00	45.00	1.00	5,315,625	558,140,625
378	-1		175.00	9.00	75.00	7,875.00	45.00	1.00	5,315,625	558,140,625
379	6	g	175.00	9.00	75.00	13,125.00	45.00	1.00	5,315,625	930,234,375
380	-1		175.00	9.00	75.00	2,625.00	45.00	1.00	5,315,625	186,046,875
513	3	p	175.00	7.00	75.00	4,725.00	35.00	5.00	16,078,125	1,012,921,875
516	-1		175.00	9.00	21.00	5,145.00	45.00	5.00	7,441,875	1,823,259,375
518	4	p	175.00	7.00	63.00	1,701.00	45.00	1.00	3,472,875	93,767,625
735	1	p	175.00	1.00	125.00	28,125.00	5.00	1.00	109,375	24,609,375
740	27	g	175.00	9.00	125.00	28,125.00	45.00	1.00	8,859,375	1,993,359,375
742	2	g	225.00	5.00	125.00	16,875.00	15.00	1.00	2,109,375	284,765,625
743	1	p	175.00	5.00	125.00	16,875.00	35.00	7.00	26,796,875	3,617,578,125
744	10	p	175.00	7.00	125.00	16,875.00	45.00	1.00	6,890,625	930,234,375
745	6	p	175.00	9.00	125.00	5,625.00	45.00	3.00	26,578,125	1,196,015,625
805	23	g	225.00	9.00	125.00	16,875.00	27.00	1.00	6,834,375	922,640,625
808	4	p	175.00	7.00	75.00	7,875.00	21.00	3.00	5,788,125	607,753,125
809	12	g	175.00	9.00	125.00	21,875.00	35.00	1.00	6,890,625	1,205,859,375
810	-1		175.00	9.00	125.00	16,875.00	45.00	3.00	26,578,125	3,588,046,875
812	11	p	175.00	9.00	125.00	28,125.00	45.00	1.00	8,859,375	1,993,359,375
816	2	p	175.00	7.00	75.00	13,125.00	35.00	3.00	9,646,875	1,688,203,125
817	-1		175.00	9.00	75.00	7,875.00	45.00	1.00	5,315,625	558,140,625
888	14	p	175.00	9.00	125.00	16,875.00	45.00	1.00	8,859,375	1,196,015,625
963	-1		225.00	9.00	175.00	25,725.00	45.00	7.00	111,628,125	16,409,334,375
965	-1		175.00	9.00	175.00	25,725.00	63.00	3.00	52,093,125	7,657,689,375
984	13	p	225.00	9.00	175.00	55,125.00	25.00	3.00	26,578,125	8,372,109,375
1126	1	g	225.00	5.00	125.00	16,875.00	45.00	1.00	6,328,125	854,296,875
1129	1	p	175.00	9.00	125.00	16,875.00	45.00	1.00	8,859,375	1,196,015,625
1130	13	p	175.00	9.00	125.00	16,875.00	45.00	1.00	8,859,375	1,196,015,625
1262	26	g	175.00	9.00	343.00	46,305.00	63.00	5.00	170,170,875	22,973,068,125
1282	14	p	175.00	9.00	245.00	25,725.00	63.00	3.00	72,930,375	7,657,689,375
1405	4	g	175.00	7.00	125.00	16,875.00	45.00	1.00	6,890,625	930,234,375
1406	2	p	175.00	9.00	125.00	16,875.00	45.00	1.00	8,859,375	1,196,015,625
1407	5	p	175.00	7.00	75.00	16,875.00	35.00	3.00	9,646,875	2,170,546,875
1409	6	p	175.00	9.00	175.00	39,375.00	45.00	1.00	12,403,125	2,790,703,125
1410	3	g	175.00	7.00	175.00	23,625.00	21.00	1.00	4,501,875	607,753,125
1538	2	p	125.00	7.00	189.00	567.00	49.00	5.00	40,516,875	121,550,625
1540	11	p	75.00	9.00	315.00	2,835.00	35.00	5.00	37,209,375	334,884,375
1544	-1		75.00	9.00	315.00	4,725.00	45.00	1.00	9,568,125	143,521,875
1608	2	p	225.00	9.00	245.00	36,015.00	63.00	3.00	93,767,625	13,783,840,875
1754	19	p	175.00	9.00	125.00	28,125.00	27.00	1.00	5,315,625	1,196,015,625
1764	-1		175.00	9.00	125.00	28,125.00	27.00	1.00	5,315,625	1,196,015,625
1770	-1		175.00	9.00	45.00	4,725.00	63.00	1.00	4,465,125	468,838,125
1809	1	p	75.00	9.00	315.00	70,875.00	49.00	1.00	10,418,625	2,344,190,625
1810	-1		25.00	9.00	441.00	59,535.00	81.00	1.00	8,037,225	1,085,025,375
1943	-1		175.00	9.00	343.00	64,827.00	45.00	1.00	24,310,125	4,594,613,625
1948	2	p	175.00	7.00	343.00	77,175.00	49.00	1.00	20,588,575	4,632,429,375
1955	12	p	105.00	9.00	343.00	21,609.00	27.00	1.00	8,751,645	551,353,635
1956	3	p	175.00	9.00	343.00	77,175.00	45.00	1.00	24,310,125	5,469,778,125
1961	25	g	175.00	9.00	343.00	21,609.00	27.00	1.00	14,586,075	918,922,725
1967	1	p	225.00	7.00	245.00	55,125.00	45.00	1.00	17,364,375	3,906,984,375
1976	-1		135.00	9.00	343.00	21,609.00	27.00	1.00	11,252,115	708,883,245
1978	11	p	225.00	9.00	343.00	77,175.00	45.00	1.00	31,255,875	7,032,571,875
1979	3	p	225.00	7.00	125.00	5,625.00	27.00	1.00	5,315,625	239,203,125
1980	3	p	175.00	7.00	343.00	21,609.00	45.00	1.00	18,907,875	1,191,196,125
1982	-1		175.00	9.00	343.00	21,609.00	45.00	1.00	24,310,125	1,531,537,875
1983	12	p	225.00	9.00	343.00	21,609.00	35.00	1.00	24,310,125	1,531,537,875
1987	10	p	225.00	7.00	343.00	108,045.00	35.00	1.00	18,907,875	5,955,980,625

Table I.5 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
1989	15	p	175.00	9.00	343.00	108,045.00	27.00	1.00	14,586,075	4,594,613,625
2011	-1		175.00	9.00	343.00	46,305.00	27.00	1.00	14,586,075	1,969,120,125
2012	31	g	45.00	9.00	343.00	46,305.00	45.00	1.00	6,251,175	843,908,625
2014	16	p	63.00	9.00	343.00	46,305.00	45.00	1.00	8,751,645	1,181,472,075
2017	-1		175.00	9.00	343.00	15,435.00	45.00	1.00	24,310,125	1,093,955,625
2018	8	p	175.00	9.00	343.00	77,175.00	27.00	1.00	14,586,075	3,281,866,875
2019	24	p	175.00	9.00	343.00	77,175.00	45.00	1.00	24,310,125	5,469,778,125
2021	13	p	225.00	9.00	175.00	55,125.00	27.00	3.00	28,704,375	9,041,878,125
2023	12	g	225.00	9.00	343.00	77,175.00	7.00	1.00	4,862,025	1,093,955,625
2025	2	p	225.00	5.00	175.00	39,375.00	21.00	1.00	4,134,375	930,234,375
2026	22	p	225.00	9.00	343.00	77,175.00	45.00	1.00	31,255,875	7,032,571,875
2030	12	g	225.00	9.00	343.00	64,827.00	45.00	1.00	31,255,875	5,907,360,375
2032	-1		225.00	9.00	343.00	77,175.00	63.00	1.00	43,758,225	9,845,600,625
2033	12	p	225.00	9.00	343.00	108,045.00	35.00	1.00	24,310,125	7,657,689,375
2108	1	p	225.00	7.00	343.00	46,305.00	35.00	1.00	18,907,875	2,552,563,125
2111	5	p	225.00	1.00	343.00	46,305.00	9.00	1.00	694,575	93,767,625
2113	4	p	175.00	3.00	343.00	46,305.00	9.00	7.00	11,344,725	1,531,537,875
2211	5	g	225.00	7.00	175.00	23,625.00	9.00	1.00	2,480,625	334,884,375
2214	5	p	175.00	7.00	175.00	39,375.00	45.00	1.00	9,646,875	2,170,546,875
2216	13	p	175.00	9.00	175.00	39,375.00	45.00	1.00	12,403,125	2,790,703,125
2217	0	p	225.00	7.00	175.00	23,625.00	35.00	1.00	9,646,875	1,302,328,125
2218	11	p	225.00	9.00	175.00	39,375.00	27.00	1.00	9,568,125	2,152,828,125
2219	3	g	175.00	9.00	135.00	3,645.00	45.00	1.00	9,568,125	258,339,375
2220	-1		175.00	9.00	175.00	23,625.00	27.00	1.00	7,441,875	1,004,653,125
2310	4	p	225.00	9.00	175.00	33,075.00	45.00	1.00	15,946,875	3,013,959,375
2314	6	p	225.00	9.00	125.00	16,875.00	21.00	1.00	5,315,625	717,609,375
2316	6	p	175.00	9.00	175.00	11,025.00	27.00	1.00	7,441,875	468,838,125
2317	2	g	225.00	1.00	175.00	7,875.00	5.00	3.00	590,625	26,578,125
2323	3	p	175.00	3.00	245.00	55,125.00	15.00	1.00	1,929,375	434,109,375
2407	14	p	175.00	9.00	63.00	5,103.00	35.00	3.00	10,418,625	843,908,625
2409	-1		225.00	9.00	245.00	36,015.00	27.00	3.00	40,186,125	5,907,360,375
2410	2	p	225.00	7.00	245.00	36,015.00	35.00	3.00	40,516,875	5,955,980,625
2510	-1		175.00	9.00	245.00	33,075.00	27.00	1.00	10,418,625	1,406,514,375
2609	-1		175.00	9.00	245.00	36,015.00	27.00	3.00	31,255,875	4,594,613,625
2613	2	p	175.00	5.00	245.00	8,575.00	35.00	1.00	7,503,125	262,609,375
2615	3	p	175.00	7.00	245.00	36,015.00	7.00	3.00	6,302,625	926,485,875
2747	-1		175.00	9.00	343.00	77,175.00	27.00	1.00	14,586,075	3,281,866,875
2764	12	p	105.00	9.00	343.00	77,175.00	27.00	1.00	8,751,645	1,969,120,125
2766	1	g	175.00	9.00	343.00	77,175.00	27.00	1.00	14,586,075	3,281,866,875
2767	14	p	105.00	9.00	343.00	64,827.00	15.00	1.00	4,862,025	918,922,725
2768	12	p	135.00	7.00	343.00	108,045.00	27.00	1.00	8,751,645	2,756,768,175
2769	8	p	105.00	5.00	567.00	25,515.00	21.00	1.00	6,251,175	281,302,875
2770	2	p	225.00	5.00	343.00	46,305.00	35.00	1.00	13,505,625	1,823,259,375
2772	3	p	225.00	9.00	343.00	77,175.00	21.00	1.00	14,586,075	3,281,866,875
2773	4	p	225.00	9.00	343.00	64,827.00	21.00	1.00	14,586,075	2,756,768,175
2775	2	p	225.00	7.00	441.00	83,349.00	35.00	1.00	24,310,125	4,594,613,625
2776	3	p	175.00	5.00	343.00	108,045.00	21.00	1.00	6,302,625	1,985,326,875
2779	3	p	175.00	5.00	343.00	15,435.00	25.00	1.00	7,503,125	337,640,625
2780	7	g	175.00	9.00	343.00	108,045.00	45.00	1.00	24,310,125	7,657,689,375
2782	-1		175.00	9.00	567.00	25,515.00	45.00	1.00	40,186,125	1,808,375,625
2832	3	g	175.00	9.00	441.00	27,783.00	27.00	1.00	18,753,525	1,181,472,075
2833	10	g	175.00	7.00	343.00	108,045.00	27.00	3.00	34,034,175	10,720,765,125
2834	14	p	225.00	9.00	441.00	59,535.00	27.00	1.00	24,111,675	3,255,076,125
2841	4	p	175.00	9.00	343.00	21,609.00	45.00	1.00	24,310,125	1,531,537,875
2842	2	p	175.00	9.00	441.00	99,225.00	45.00	1.00	31,255,875	7,032,571,875
2909	3	p	175.00	7.00	75.00	16,875.00	45.00	1.00	4,134,375	930,234,375
2910	7	g	175.00	7.00	45.00	2,025.00	35.00	3.00	5,788,125	260,465,625
2912	-1		175.00	9.00	75.00	13,125.00	63.00	3.00	22,325,625	3,906,984,375
2914	4	g	175.00	7.00	125.00	16,875.00	35.00	3.00	16,078,125	2,170,546,875
3024	11	p	225.00	9.00	175.00	39,375.00	27.00	1.00	9,568,125	2,152,828,125
3027	5	g	225.00	5.00	175.00	23,625.00	25.00	1.00	4,921,875	664,453,125
3029	8	p	175.00	7.00	175.00	39,375.00	27.00	1.00	5,788,125	1,302,328,125

Table I.5 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
3032	-1		175.00	9.00	175.00	33,075.00	63.00	1.00	17,364,375	3,281,866,875
3033	-1		225.00	9.00	125.00	16,875.00	63.00	1.00	15,946,875	2,152,828,125
3034	-1		175.00	9.00	175.00	33,075.00	45.00	1.00	12,403,125	2,344,190,625
3106	-1		125.00	9.00	567.00	15,309.00	63.00	1.00	40,186,125	1,085,025,375
3203	12	p	125.00	9.00	245.00	55,125.00	21.00	3.00	17,364,375	3,906,984,375
3208	2	g	225.00	5.00	315.00	70,875.00	35.00	1.00	12,403,125	2,790,703,125
3210	-1		75.00	9.00	315.00	14,175.00	81.00	1.00	17,222,625	775,018,125
3403	3	p	225.00	7.00	343.00	36,015.00	25.00	5.00	67,528,125	7,090,453,125
3408	-1		175.00	9.00	343.00	8,575.00	81.00	1.00	43,758,225	1,093,955,625
3487	5	p	175.00	9.00	343.00	60,025.00	45.00	5.00	121,550,625	21,271,359,375
3488	1	p	175.00	5.00	343.00	8,575.00	15.00	3.00	13,505,625	337,640,625
3514	-1		125.00	9.00	45.00	1,215.00	63.00	1.00	3,189,375	86,113,125
3515	10	g	75.00	7.00	27.00	2,187.00	45.00	1.00	637,875	51,667,875
3516	1	p	175.00	7.00	135.00	675.00	45.00	1.00	7,441,875	37,209,375
3517	-1		125.00	9.00	45.00	675.00	45.00	1.00	2,278,125	34,171,875
3627	-1		175.00	9.00	175.00	23,625.00	63.00	1.00	17,364,375	2,344,190,625
3641	14	p	105.00	9.00	175.00	39,375.00	45.00	1.00	7,441,875	1,674,421,875
3646	-1		175.00	9.00	175.00	23,625.00	63.00	1.00	17,364,375	2,344,190,625
3651	2	g	135.00	5.00	175.00	23,625.00	21.00	1.00	2,480,625	334,884,375
3652	2	p	175.00	7.00	175.00	18,375.00	45.00	1.00	9,646,875	1,012,921,875
3654	2	p	175.00	7.00	175.00	18,375.00	35.00	3.00	22,509,375	2,363,484,375
3655	12	p	175.00	9.00	75.00	5,625.00	45.00	1.00	5,315,625	398,671,875
3825	5	p	225.00	7.00	343.00	46,305.00	45.00	1.00	24,310,125	3,281,866,875
3835	8	p	63.00	9.00	343.00	64,827.00	27.00	1.00	5,250,987	992,436,543
3864	11	p	135.00	9.00	343.00	108,045.00	45.00	1.00	18,753,525	5,907,360,375
3865	12	p	135.00	9.00	343.00	46,305.00	7.00	1.00	2,917,215	393,824,025
3866	2	g	225.00	5.00	343.00	108,045.00	3.00	3.00	3,472,875	1,093,955,625
3867	23	p	135.00	9.00	343.00	108,045.00	45.00	1.00	18,753,525	5,907,360,375
3868	8	p	225.00	7.00	245.00	55,125.00	27.00	1.00	10,418,625	2,344,190,625
3872	6	p	125.00	7.00	343.00	46,305.00	35.00	1.00	10,504,375	1,418,090,625
3874	10	g	225.00	9.00	343.00	64,827.00	21.00	1.00	14,586,075	2,756,768,175
3875	-1		175.00	9.00	343.00	64,827.00	45.00	1.00	24,310,125	4,594,613,625
3882	-1		175.00	9.00	343.00	64,827.00	45.00	1.00	24,310,125	4,594,613,625
3911	-1		125.00	9.00	105.00	14,175.00	35.00	1.00	4,134,375	558,140,625
3913	5	p	175.00	7.00	175.00	23,625.00	35.00	3.00	22,509,375	3,038,765,625
3914	2	g	175.00	9.00	63.00	5,103.00	27.00	1.00	2,679,075	217,005,075
3915	-1		175.00	9.00	175.00	39,375.00	27.00	3.00	22,325,625	5,023,265,625
4025	-1		75.00	9.00	315.00	70,875.00	63.00	1.00	13,395,375	3,013,959,375
4026	-1		25.00	9.00	441.00	59,535.00	81.00	1.00	8,037,225	1,085,025,375
4149	3	p	175.00	5.00	343.00	64,827.00	35.00	1.00	10,504,375	1,985,326,875
4152	19	p	75.00	9.00	343.00	64,827.00	21.00	3.00	14,586,075	2,756,768,175
4158	12	p	225.00	9.00	343.00	77,175.00	45.00	1.00	31,255,875	7,032,571,875
4159	21	p	105.00	9.00	343.00	64,827.00	27.00	1.00	8,751,645	1,654,060,905
4162	18	p	225.00	9.00	343.00	64,827.00	35.00	3.00	72,930,375	13,783,840,875
4166	-1		175.00	9.00	245.00	36,015.00	45.00	5.00	86,821,875	12,762,815,625
4169	2	p	175.00	5.00	343.00	46,305.00	25.00	5.00	37,515,625	5,064,609,375
4171	2	g	225.00	7.00	343.00	15,435.00	35.00	5.00	94,539,375	4,254,271,875
4172	-1		175.00	9.00	343.00	108,045.00	27.00	5.00	72,930,375	22,973,068,125
4173	-1		225.00	9.00	343.00	46,305.00	63.00	5.00	218,791,125	29,536,801,875
4178	3	p	175.00	7.00	343.00	77,175.00	49.00	1.00	20,588,575	4,632,429,375
4279	-1		175.00	9.00	245.00	36,015.00	81.00	1.00	31,255,875	4,594,613,625
4286	4	p	225.00	9.00	245.00	12,005.00	63.00	3.00	93,767,625	4,594,613,625
4287	3	p	225.00	9.00	245.00	25,725.00	45.00	3.00	66,976,875	7,032,571,875
4413	2	p	25.00	7.00	315.00	14,175.00	63.00	1.00	3,472,875	156,279,375
4416	18	p	125.00	9.00	315.00	42,525.00	63.00	1.00	22,325,625	3,013,959,375
4417	8	g	125.00	9.00	315.00	42,525.00	81.00	1.00	28,704,375	3,875,090,625
4418	-1		25.00	9.00	189.00	8,505.00	63.00	1.00	2,679,075	120,558,375
4635	-1		175.00	9.00	175.00	25,725.00	45.00	1.00	12,403,125	1,823,259,375
4643	-1		175.00	7.00	175.00	30,625.00	35.00	1.00	7,503,125	1,313,046,875
4645	-1		225.00	9.00	245.00	19,845.00	63.00	1.00	31,255,875	2,531,725,875
4650	4	p	175.00	7.00	175.00	8,575.00	63.00	1.00	13,505,625	661,775,625
4654	-1		175.00	9.00	175.00	39,375.00	81.00	1.00	22,325,625	5,023,265,625

Table I.5 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
4724	14	p	125.00	9.00	315.00	42,525.00	63.00	1.00	22,325,625	3,013,959,375
4732	2	p	125.00	9.00	441.00	35,721.00	45.00	1.00	22,325,625	1,808,375,625
4735	-1		75.00	9.00	315.00	42,525.00	27.00	1.00	5,740,875	775,018,125
4738	-1		25.00	7.00	441.00	15,435.00	49.00	1.00	3,781,575	132,355,125
4739	-1		25.00	9.00	315.00	42,525.00	45.00	1.00	3,189,375	430,565,625
4801	2	p	225.00	3.00	245.00	11,025.00	25.00	1.00	4,134,375	186,046,875
4802	3	p	225.00	3.00	245.00	11,025.00	25.00	1.00	4,134,375	186,046,875
4803	9	g	225.00	9.00	343.00	46,305.00	45.00	3.00	93,767,625	12,658,629,375
4921	5	p	175.00	7.00	343.00	108,045.00	49.00	1.00	20,588,575	6,485,401,125
4925	-1		175.00	9.00	343.00	64,827.00	45.00	1.00	24,310,125	4,594,613,625
4933	-1		225.00	7.00	441.00	59,535.00	45.00	1.00	31,255,875	4,219,543,125
4940	1	g	225.00	7.00	343.00	108,045.00	35.00	1.00	18,907,875	5,955,980,625
6155	9	p	225.00	3.00	343.00	64,827.00	35.00	5.00	40,516,875	7,657,689,375
6159	3	p	225.00	9.00	343.00	108,045.00	27.00	1.00	18,753,525	5,907,360,375
6160	2	p	225.00	5.00	343.00	46,305.00	49.00	3.00	56,723,625	7,657,689,375
6161	-1		225.00	9.00	343.00	46,305.00	45.00	1.00	31,255,875	4,219,543,125
6168	3	p	175.00	5.00	343.00	108,045.00	21.00	5.00	31,513,125	9,926,634,375
6172	9	p	175.00	7.00	343.00	64,827.00	63.00	5.00	132,355,125	25,015,118,625
6173	4	g	175.00	9.00	343.00	108,045.00	63.00	1.00	34,034,175	10,720,765,125
6174	4	g	175.00	7.00	343.00	46,305.00	25.00	5.00	52,521,875	7,090,453,125
6176	4	g	175.00	9.00	343.00	46,305.00	81.00	5.00	218,791,125	29,536,801,875
6220	33	g	105.00	9.00	245.00	25,725.00	45.00	5.00	52,093,125	5,469,778,125
6225	20	p	175.00	9.00	343.00	36,015.00	45.00	3.00	72,930,375	7,657,689,375
6313	9	p	225.00	9.00	21.00	189.00	9.00	1.00	382,725	3,444,525
6321	1	p	175.00	3.00	21.00	2,205.00	15.00	7.00	1,157,625	121,550,625
6322	-1		175.00	9.00	15.00	315.00	27.00	3.00	1,913,625	40,186,125
6335	5	g	105.00	7.00	45.00	3,375.00	35.00	1.00	1,157,625	86,821,875
6339	13	p	175.00	9.00	15.00	945.00	21.00	3.00	1,488,375	93,767,625
6341	5	p	125.00	7.00	15.00	1,575.00	9.00	3.00	354,375	37,209,375
6343	4	p	125.00	9.00	15.00	315.00	9.00	3.00	455,625	9,568,125
6350	7	p	175.00	7.00	15.00	2,625.00	35.00	7.00	4,501,875	787,828,125
6351	2	p	125.00	7.00	75.00	1,875.00	27.00	1.00	1,771,875	44,296,875
6363	5	p	175.00	7.00	45.00	3,375.00	45.00	1.00	2,480,625	186,046,875
6364	11	g	175.00	7.00	21.00	735.00	45.00	3.00	3,472,875	121,550,625
6367	6	g	125.00	9.00	15.00	1,575.00	35.00	1.00	590,625	62,015,625
6369	9	p	125.00	9.00	75.00	5,625.00	27.00	1.00	2,278,125	170,859,375
6371	-1		175.00	7.00	15.00	1,575.00	35.00	5.00	3,215,625	337,640,625
6372	2	g	175.00	9.00	15.00	315.00	27.00	5.00	3,189,375	66,976,875
6373	13	p	175.00	9.00	15.00	375.00	45.00	1.00	1,063,125	26,578,125
6374	-1		175.00	9.00	45.00	1,575.00	45.00	1.00	3,189,375	111,628,125
6375	20	p	175.00	9.00	15.00	2,625.00	35.00	1.00	826,875	144,703,125
6376	8	p	175.00	9.00	15.00	1,575.00	7.00	3.00	496,125	52,093,125
6377	14	g	225.00	9.00	75.00	7,875.00	21.00	1.00	3,189,375	334,884,375
6378	-1		125.00	9.00	15.00	315.00	45.00	5.00	3,796,875	79,734,375
6379	0	p	125.00	7.00	15.00	945.00	35.00	7.00	3,215,625	202,584,375
6380	-1		175.00	9.00	21.00	2,205.00	63.00	1.00	2,083,725	218,791,125
6517	8	p	175.00	9.00	105.00	14,175.00	45.00	3.00	22,325,625	3,013,959,375
6538	11	p	175.00	7.00	63.00	8,505.00	21.00	1.00	1,620,675	218,791,125
6555	5	g	175.00	9.00	63.00	8,505.00	35.00	1.00	3,472,875	468,838,125
6556	6	p	75.00	9.00	63.00	14,175.00	27.00	1.00	1,148,175	258,339,375
6559	1	p	175.00	5.00	63.00	6,615.00	35.00	3.00	5,788,125	607,753,125
6561	3	p	125.00	7.00	75.00	13,125.00	35.00	3.00	6,890,625	1,205,859,375
6563	1	p	175.00	7.00	63.00	8,505.00	21.00	1.00	1,620,675	218,791,125
6567	6	p	175.00	7.00	75.00	5,625.00	5.00	1.00	459,375	34,453,125
6570	3	g	125.00	7.00	63.00	8,505.00	7.00	1.00	385,875	52,093,125
6574	8	p	175.00	9.00	105.00	14,175.00	27.00	1.00	4,465,125	602,791,875
6577	28	p	175.00	9.00	21.00	5,145.00	27.00	3.00	2,679,075	656,373,375
6578	9	g	105.00	9.00	75.00	11,025.00	27.00	3.00	5,740,875	843,908,625
6580	13	p	175.00	9.00	75.00	16,875.00	63.00	1.00	7,441,875	1,674,421,875
6581	13	p	175.00	9.00	63.00	8,505.00	35.00	1.00	3,472,875	468,838,125
6585	2	p	175.00	5.00	63.00	14,175.00	15.00	5.00	4,134,375	930,234,375
6587	7	p	175.00	7.00	105.00	25,725.00	35.00	3.00	13,505,625	3,308,878,125

Table I.5 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
6588	3	p	175.00	9.00	63.00	5,103.00	45.00	1.00	4,465,125	361,675,125
6589	2	p	225.00	9.00	63.00	14,175.00	45.00	3.00	17,222,625	3,875,090,625
6806	-1		175.00	9.00	75.00	7,875.00	81.00	1.00	9,568,125	1,004,653,125
6807	12	p	175.00	9.00	81.00	10,935.00	45.00	1.00	5,740,875	775,018,125
6814	2	p	175.00	5.00	63.00	2,835.00	25.00	5.00	6,890,625	310,078,125
6816	-1		175.00	9.00	63.00	8,505.00	45.00	7.00	31,255,875	4,219,543,125
6817	-1		175.00	9.00	63.00	14,175.00	9.00	7.00	6,251,175	1,406,514,375
6819	-1		175.00	9.00	75.00	2,625.00	45.00	1.00	5,315,625	186,046,875
6820	-1		175.00	9.00	81.00	10,935.00	45.00	1.00	5,740,875	775,018,125
6918	-1		175.00	9.00	125.00	16,875.00	63.00	1.00	12,403,125	1,674,421,875
6951	-1		175.00	9.00	21.00	2,205.00	63.00	1.00	2,083,725	218,791,125
6954	2	g	175.00	7.00	343.00	77,175.00	35.00	1.00	14,706,125	3,308,878,125
6959	-1		175.00	9.00	45.00	1,575.00	81.00	1.00	5,740,875	200,930,625
8413	-1		175.00	9.00	125.00	16,875.00	63.00	1.00	12,403,125	1,674,421,875
8418	4	p	175.00	7.00	63.00	2,835.00	35.00	5.00	13,505,625	607,753,125
8419	1	p	175.00	9.00	75.00	2,625.00	45.00	1.00	5,315,625	186,046,875
8429	2	p	175.00	5.00	245.00	33,075.00	35.00	1.00	7,503,125	1,012,921,875
8431	-1		175.00	9.00	343.00	64,827.00	45.00	1.00	24,310,125	4,594,613,625
8437	-1		175.00	5.00	63.00	11,025.00	35.00	1.00	1,929,375	337,640,625
8438	-1		175.00	9.00	63.00	2,835.00	45.00	5.00	22,325,625	1,004,653,125
8439	-1		175.00	7.00	63.00	2,835.00	35.00	1.00	2,701,125	121,550,625
8444	-1		175.00	9.00	15.00	1,125.00	45.00	9.00	9,568,125	717,609,375
8446	-1		175.00	9.00	75.00	13,125.00	45.00	1.00	5,315,625	930,234,375
8447	-1		175.00	9.00	15.00	1,575.00	63.00	1.00	1,488,375	156,279,375
8454	-1		175.00	9.00	63.00	2,835.00	45.00	1.00	4,465,125	200,930,625
8469	1	p	175.00	3.00	125.00	28,125.00	21.00	7.00	9,646,875	2,170,546,875
8518	-1		175.00	9.00	75.00	13,125.00	45.00	1.00	5,315,625	930,234,375
8519	-1		175.00	9.00	21.00	5,145.00	63.00	1.00	2,083,725	510,512,625
8520	-1		125.00	9.00	63.00	2,205.00	45.00	1.00	3,189,375	111,628,125
8521	-1		175.00	9.00	63.00	14,175.00	63.00	7.00	43,758,225	9,845,600,625
8523	-1		75.00	9.00	27.00	2,187.00	63.00	1.00	1,148,175	93,002,175
8527	-1		175.00	9.00	105.00	3,675.00	81.00	1.00	13,395,375	468,838,125
8531	4	p	175.00	9.00	75.00	7,875.00	45.00	1.00	5,315,625	558,140,625
8537	8	p	175.00	7.00	75.00	10,125.00	35.00	3.00	9,646,875	1,302,328,125
8539	-1		175.00	9.00	63.00	2,835.00	63.00	1.00	6,251,175	281,302,875
8540	1	p	175.00	5.00	75.00	10,125.00	15.00	3.00	2,953,125	398,671,875
8545	-1		175.00	9.00	15.00	945.00	81.00	1.00	1,913,625	120,558,375
8550	1	g	175.00	7.00	245.00	77,175.00	49.00	1.00	14,706,125	4,632,429,375
8561	-1		25.00	9.00	63.00	19,845.00	45.00	1.00	637,875	200,930,625
8563	-1		25.00	9.00	63.00	11,907.00	81.00	1.00	1,148,175	217,005,075
8577	-1		175.00	9.00	125.00	28,125.00	63.00	1.00	12,403,125	2,790,703,125
8583	-1		25.00	9.00	315.00	42,525.00	81.00	1.00	5,740,875	775,018,125
8598	-1		175.00	9.00	343.00	21,609.00	45.00	1.00	24,310,125	1,531,537,875
8913	2	p	175.00	7.00	175.00	6,125.00	35.00	1.00	7,503,125	262,609,375
8916	1	g	225.00	7.00	125.00	5,625.00	49.00	1.00	9,646,875	434,109,375
8918	-1		175.00	9.00	343.00	15,435.00	45.00	1.00	24,310,125	1,093,955,625
8919	-1		175.00	9.00	125.00	16,875.00	63.00	3.00	37,209,375	5,023,265,625
8922	10	p	175.00	9.00	175.00	39,375.00	27.00	3.00	22,325,625	5,023,265,625
8924	7	p	175.00	7.00	125.00	16,875.00	35.00	1.00	5,359,375	723,515,625
8926	-1		175.00	9.00	15.00	2,625.00	45.00	1.00	1,063,125	186,046,875
8929	5	p	175.00	7.00	21.00	5,145.00	45.00	3.00	3,472,875	850,854,375
8931	12	p	175.00	9.00	343.00	36,015.00	45.00	3.00	72,930,375	7,657,689,375
8941	-1		125.00	9.00	315.00	42,525.00	63.00	1.00	22,325,625	3,013,959,375
8951	-1		175.00	9.00	63.00	8,505.00	63.00	3.00	18,753,525	2,531,725,875
8955	-1		175.00	9.00	245.00	15,435.00	63.00	1.00	24,310,125	1,531,537,875
8964	-1		75.00	9.00	189.00	8,505.00	63.00	1.00	8,037,225	361,675,125
8966	-1		25.00	9.00	441.00	35,721.00	81.00	1.00	8,037,225	651,015,225
8976	-1		175.00	9.00	63.00	8,505.00	63.00	1.00	6,251,175	843,908,625
8984	-1		175.00	9.00	175.00	23,625.00	9.00	1.00	2,480,625	334,884,375
8994	7	p	175.00	9.00	175.00	11,025.00	27.00	1.00	7,441,875	468,838,125
8996	-1		175.00	9.00	343.00	108,045.00	81.00	1.00	43,758,225	13,783,840,875
8998	-1		125.00	9.00	63.00	441.00	63.00	1.00	4,465,125	31,255,875

Table I.6 ESL Derived from Factor Classes (multiplied sub-factors) and ISO Suggested Coding

Store ID	First leaks	Types	Factor A	Factor C	Factor E	FactorE1	Factor F	Factor G	ESL	ESL+ extra
164	5	g	0.998	1.000	1.000	1.045	0.945	0.900	0.848	0.887
170	-1		1.050	1.100	0.950	0.903	1.100	0.900	1.086	1.032
172	13	p	0.998	1.100	1.000	1.045	1.045	0.900	1.032	1.078
201	-1		1.050	1.100	0.855	0.812	1.100	0.950	1.032	0.980
374	12	p	1.050	1.100	0.950	0.948	1.100	0.900	1.086	1.084
375	9	p	1.050	1.050	0.950	0.948	0.998	0.950	0.993	0.990
376	-1		1.050	1.100	0.950	0.948	1.100	0.900	1.086	1.084
378	-1		1.050	1.100	0.950	0.948	1.100	0.900	1.086	1.084
379	6	g	1.050	1.100	0.950	0.998	1.100	0.900	1.086	1.141
380	-1		1.050	1.100	0.950	0.898	1.100	0.900	1.086	1.027
513	3	p	1.050	1.050	0.950	0.988	1.050	1.000	1.100	1.143
516	-1		1.050	1.100	0.898	0.990	1.100	1.000	1.141	1.258
518	4	p	1.050	1.050	0.948	0.891	1.100	0.900	1.034	0.973
735	1	p	1.050	0.900	1.000	1.100	0.900	0.900	0.765	0.842
740	27	g	1.050	1.100	1.000	1.100	1.100	0.900	1.143	1.258
742	2	g	1.100	1.000	1.000	1.045	0.950	0.900	0.941	0.983
743	1	p	1.050	1.000	1.000	1.045	1.050	1.050	1.158	1.210
744	10	p	1.050	1.050	1.000	1.045	1.100	0.900	1.091	1.141
745	6	p	1.050	1.100	1.000	0.990	1.100	0.950	1.207	1.195
805	23	g	1.100	1.100	1.000	1.045	1.045	0.900	1.138	1.189
808	4	p	1.050	1.050	0.950	0.948	0.998	0.950	0.993	0.990
809	12	g	1.050	1.100	1.000	1.050	1.050	0.900	1.091	1.146
810	-1		1.050	1.100	1.000	1.045	1.100	0.950	1.207	1.261
812	11	p	1.050	1.100	1.000	1.100	1.100	0.900	1.143	1.258
816	2	p	1.050	1.050	0.950	0.998	1.050	0.950	1.045	1.097
817	-1		1.050	1.100	0.950	0.948	1.100	0.900	1.086	1.084
888	14	p	1.050	1.100	1.000	1.045	1.100	0.900	1.143	1.195
963	-1		1.100	1.100	1.050	1.100	1.100	1.050	1.467	1.537
965	-1		1.050	1.100	1.050	1.100	1.155	0.950	1.331	1.394
984	13	p	1.100	1.100	1.050	1.213	1.000	0.950	1.207	1.394
1126	1	g	1.100	1.000	1.000	1.045	1.100	0.900	1.089	1.138
1129	1	p	1.050	1.100	1.000	1.045	1.100	0.900	1.143	1.195
1130	13	p	1.050	1.100	1.000	1.045	1.100	0.900	1.143	1.195
1262	26	g	1.050	1.100	1.158	1.210	1.155	1.000	1.544	1.614
1282	14	p	1.050	1.100	1.103	1.100	1.155	0.950	1.397	1.394
1405	4	g	1.050	1.050	1.000	1.045	1.100	0.900	1.091	1.141
1406	2	p	1.050	1.100	1.000	1.045	1.100	0.900	1.143	1.195
1407	5	p	1.050	1.050	0.950	1.045	1.050	0.950	1.045	1.149
1409	6	p	1.050	1.100	1.050	1.155	1.100	0.900	1.201	1.321
1410	3	g	1.050	1.050	1.050	1.097	0.998	0.900	1.039	1.086
1538	2	p	1.000	1.050	1.097	0.844	1.103	1.000	1.270	0.977
1540	11	p	0.950	1.100	1.155	0.938	1.050	1.000	1.267	1.029
1544	-1		0.950	1.100	1.155	0.988	1.100	0.900	1.195	1.022
1608	2	p	1.100	1.100	1.103	1.155	1.155	0.950	1.464	1.533
1754	19	p	1.050	1.100	1.000	1.100	1.045	0.900	1.086	1.195
1764	-1		1.050	1.100	1.000	1.100	1.045	0.900	1.086	1.195
1770	-1		1.050	1.100	0.903	0.900	1.155	0.900	1.084	1.081
1809	1	p	0.950	1.100	1.155	1.271	1.103	0.900	1.198	1.317
1810	-1		0.900	1.100	1.213	1.267	1.210	0.900	1.307	1.366
1943	-1		1.050	1.100	1.158	1.270	1.100	0.900	1.324	1.452
1948	2	p	1.050	1.050	1.158	1.273	1.103	0.900	1.266	1.393
1955	12	p	0.998	1.100	1.158	1.203	1.045	0.900	1.195	1.242
1956	3	p	1.050	1.100	1.158	1.273	1.100	0.900	1.324	1.456
1961	25	g	1.050	1.100	1.158	1.203	1.045	0.900	1.258	1.307
1967	1	p	1.100	1.050	1.103	1.213	1.100	0.900	1.261	1.387
1976	-1		1.045	1.100	1.158	1.203	1.045	0.900	1.252	1.301
1978	11	p	1.100	1.100	1.158	1.273	1.100	0.900	1.387	1.525
1979	3	p	1.100	1.050	1.000	0.990	1.045	0.900	1.086	1.075
1980	3	p	1.050	1.050	1.158	1.203	1.100	0.900	1.264	1.313
1982	-1		1.050	1.100	1.158	1.203	1.100	0.900	1.324	1.376
1983	12	p	1.100	1.100	1.158	1.203	1.050	0.900	1.324	1.376
1987	10	p	1.100	1.050	1.158	1.337	1.050	0.900	1.264	1.459

Table I.6 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	FactorE1	Factor F	Factor G	ESL	ESL+ extra
1989	15	p	1.050	1.100	1.158	1.337	1.045	0.900	1.258	1.452
2011	-1		1.050	1.100	1.158	1.210	1.045	0.900	1.258	1.314
2012	31	g	0.903	1.100	1.158	1.210	1.100	0.900	1.138	1.189
2014	16	p	0.948	1.100	1.158	1.210	1.100	0.900	1.195	1.248
2017	-1		1.050	1.100	1.158	1.146	1.100	0.900	1.324	1.310
2018	8	p	1.050	1.100	1.158	1.273	1.045	0.900	1.258	1.383
2019	24	p	1.050	1.100	1.158	1.273	1.100	0.900	1.324	1.456
2021	13	p	1.100	1.100	1.050	1.213	1.045	0.950	1.261	1.457
2023	12	g	1.100	1.100	1.158	1.273	0.945	0.900	1.191	1.310
2025	2	p	1.100	1.000	1.050	1.155	0.998	0.900	1.037	1.141
2026	22	p	1.100	1.100	1.158	1.273	1.100	0.900	1.387	1.525
2030	12	g	1.100	1.100	1.158	1.270	1.100	0.900	1.387	1.522
2032	-1		1.100	1.100	1.158	1.273	1.155	0.900	1.456	1.602
2033	12	p	1.100	1.100	1.158	1.337	1.050	0.900	1.324	1.529
2108	1	p	1.100	1.050	1.158	1.210	1.050	0.900	1.264	1.320
2111	5	p	1.100	0.900	1.158	1.210	0.903	0.900	0.931	0.973
2113	4	p	1.050	0.950	1.158	1.210	0.903	1.050	1.094	1.143
2211	5	g	1.100	1.050	1.050	1.097	0.990	0.900	1.081	1.129
2214	5	p	1.050	1.050	1.050	1.155	1.100	0.900	1.146	1.261
2216	13	p	1.050	1.100	1.050	1.155	1.100	0.900	1.201	1.321
2217	0	p	1.100	1.050	1.050	1.097	1.050	0.900	1.146	1.198
2218	11	p	1.100	1.100	1.050	1.155	1.045	0.900	1.195	1.314
2219	3	g	1.050	1.100	1.045	0.983	1.100	0.900	1.195	1.124
2220	-1		1.050	1.100	1.050	1.097	1.045	0.900	1.141	1.192
2310	4	p	1.100	1.100	1.050	1.152	1.100	0.900	1.258	1.380
2314	6	p	1.100	1.100	1.000	1.045	0.998	0.900	1.086	1.135
2316	6	p	1.050	1.100	1.050	1.091	1.045	0.900	1.141	1.186
2317	2	g	1.100	0.900	1.050	1.040	0.900	0.950	0.889	0.880
2323	3	p	1.050	0.950	1.103	1.213	0.950	0.900	0.940	1.034
2407	14	p	1.050	1.100	1.040	1.132	1.050	0.950	1.198	1.304
2409	-1		1.100	1.100	1.103	1.155	1.045	0.950	1.324	1.387
2410	2	p	1.100	1.050	1.103	1.155	1.050	0.950	1.270	1.330
2510	-1		1.050	1.100	1.103	1.152	1.045	0.900	1.198	1.252
2609	-1		1.050	1.100	1.103	1.155	1.045	0.950	1.264	1.324
2613	2	p	1.050	1.000	1.103	1.042	1.050	0.900	1.094	1.034
2615	3	p	1.050	1.050	1.103	1.155	0.945	0.950	1.091	1.143
2747	-1		1.050	1.100	1.158	1.273	1.045	0.900	1.258	1.383
2764	12	p	0.998	1.100	1.158	1.273	1.045	0.900	1.195	1.314
2766	1	g	1.050	1.100	1.158	1.273	1.045	0.900	1.258	1.383
2767	14	p	0.998	1.100	1.158	1.270	0.950	0.900	1.086	1.192
2768	12	p	1.045	1.050	1.158	1.337	1.045	0.900	1.195	1.380
2769	8	p	0.998	1.000	1.271	1.258	0.998	0.900	1.138	1.126
2770	2	p	1.100	1.000	1.158	1.210	1.050	0.900	1.203	1.258
2772	3	p	1.100	1.100	1.158	1.273	0.998	0.900	1.258	1.383
2773	4	p	1.100	1.100	1.158	1.270	0.998	0.900	1.258	1.380
2775	2	p	1.100	1.050	1.213	1.331	1.050	0.900	1.324	1.452
2776	3	p	1.050	1.000	1.158	1.337	0.998	0.900	1.091	1.260
2779	3	p	1.050	1.000	1.158	1.146	1.000	0.900	1.094	1.083
2780	7	g	1.050	1.100	1.158	1.337	1.100	0.900	1.324	1.529
2782	-1		1.050	1.100	1.271	1.258	1.100	0.900	1.453	1.438
2832	3	g	1.050	1.100	1.213	1.261	1.045	0.900	1.317	1.369
2833	10	g	1.050	1.050	1.158	1.337	1.045	0.950	1.267	1.463
2834	14	p	1.100	1.100	1.213	1.267	1.045	0.900	1.380	1.442
2841	4	p	1.050	1.100	1.158	1.203	1.100	0.900	1.324	1.376
2842	2	p	1.050	1.100	1.213	1.334	1.100	0.900	1.387	1.525
2909	3	p	1.050	1.050	0.950	1.045	1.100	0.900	1.037	1.141
2910	7	g	1.050	1.050	0.903	0.815	1.050	0.950	0.993	0.896
2912	-1		1.050	1.100	0.950	0.998	1.155	0.950	1.204	1.264
2914	4	g	1.050	1.050	1.000	1.045	1.050	0.950	1.100	1.149
3024	11	p	1.100	1.100	1.050	1.155	1.045	0.900	1.195	1.314
3027	5	g	1.100	1.000	1.050	1.097	1.000	0.900	1.040	1.086
3029	8	p	1.050	1.050	1.050	1.155	1.045	0.900	1.089	1.198

Table I.6 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	FactorE1	Factor F	Factor G	ESL	ESL+ extra
3032	-1		1.050	1.100	1.050	1.152	1.155	0.900	1.261	1.383
3033	-1		1.100	1.100	1.000	1.045	1.155	0.900	1.258	1.314
3034	-1		1.050	1.100	1.050	1.152	1.100	0.900	1.201	1.317
3106	-1		1.000	1.100	1.271	1.195	1.155	0.900	1.453	1.366
3203	12	p	1.000	1.100	1.103	1.213	0.998	0.950	1.149	1.264
3208	2	g	1.100	1.000	1.155	1.271	1.050	0.900	1.201	1.321
3210	-1		0.950	1.100	1.155	1.143	1.210	0.900	1.314	1.301
3403	3	p	1.100	1.050	1.158	1.155	1.000	1.000	1.337	1.334
3408	-1		1.050	1.100	1.158	1.042	1.210	0.900	1.456	1.310
3487	5	p	1.050	1.100	1.158	1.216	1.100	1.000	1.471	1.544
3488	1	p	1.050	1.000	1.158	1.042	0.950	0.950	1.097	0.987
3514	-1		1.000	1.100	0.990	0.931	1.155	0.900	1.132	1.065
3515	10	g	0.950	1.050	0.941	0.934	1.100	0.900	0.929	0.922
3516	1	p	1.050	1.050	1.045	0.846	1.100	0.900	1.141	0.924
3517	-1		1.000	1.100	0.990	0.846	1.100	0.900	1.078	0.922
3627	-1		1.050	1.100	1.050	1.097	1.155	0.900	1.261	1.317
3641	14	p	0.998	1.100	1.050	1.155	1.100	0.900	1.141	1.255
3646	-1		1.050	1.100	1.050	1.097	1.155	0.900	1.261	1.317
3651	2	g	1.045	1.000	1.050	1.097	0.998	0.900	0.985	1.029
3652	2	p	1.050	1.050	1.050	1.047	1.100	0.900	1.146	1.143
3654	2	p	1.050	1.050	1.050	1.047	1.050	0.950	1.155	1.152
3655	12	p	1.050	1.100	0.950	0.903	1.100	0.900	1.086	1.032
3825	5	p	1.100	1.050	1.158	1.210	1.100	0.900	1.324	1.383
3835	8	p	0.948	1.100	1.158	1.270	1.045	0.900	1.135	1.245
3864	11	p	1.045	1.100	1.158	1.337	1.100	0.900	1.317	1.522
3865	12	p	1.045	1.100	1.158	1.210	0.945	0.900	1.132	1.183
3866	2	g	1.100	1.000	1.158	1.337	0.855	0.950	1.034	1.195
3867	23	p	1.045	1.100	1.158	1.337	1.100	0.900	1.317	1.522
3868	8	p	1.100	1.050	1.103	1.213	1.045	0.900	1.198	1.317
3872	6	p	1.000	1.050	1.158	1.210	1.050	0.900	1.149	1.200
3874	10	g	1.100	1.100	1.158	1.270	0.998	0.900	1.258	1.380
3875	-1		1.050	1.100	1.158	1.270	1.100	0.900	1.324	1.452
3882	-1		1.050	1.100	1.158	1.270	1.100	0.900	1.324	1.452
3911	-1		1.000	1.100	0.998	1.042	1.050	0.900	1.037	1.084
3913	5	p	1.050	1.050	1.050	1.097	1.050	0.950	1.155	1.207
3914	2	g	1.050	1.100	0.948	0.941	1.045	0.900	1.029	1.022
3915	-1		1.050	1.100	1.050	1.155	1.045	0.950	1.204	1.324
4025	-1		0.950	1.100	1.155	1.271	1.155	0.900	1.255	1.380
4026	-1		0.900	1.100	1.213	1.267	1.210	0.900	1.307	1.366
4149	3	p	1.050	1.000	1.158	1.270	1.050	0.900	1.149	1.260
4152	19	p	0.950	1.100	1.158	1.270	0.998	0.950	1.146	1.258
4158	12	p	1.100	1.100	1.158	1.273	1.100	0.900	1.387	1.525
4159	21	p	0.998	1.100	1.158	1.270	1.045	0.900	1.195	1.311
4162	18	p	1.100	1.100	1.158	1.270	1.050	0.950	1.397	1.533
4166	-1		1.050	1.100	1.103	1.155	1.100	1.000	1.401	1.467
4169	2	p	1.050	1.000	1.158	1.210	1.000	1.000	1.216	1.270
4171	2	g	1.100	1.050	1.158	1.146	1.050	1.000	1.404	1.390
4172	-1		1.050	1.100	1.158	1.337	1.045	1.000	1.397	1.614
4173	-1		1.100	1.100	1.158	1.210	1.155	1.000	1.618	1.691
4178	3	p	1.050	1.050	1.158	1.273	1.103	0.900	1.266	1.393
4279	-1		1.050	1.100	1.103	1.155	1.210	0.900	1.387	1.452
4286	4	p	1.100	1.100	1.103	1.094	1.155	0.950	1.464	1.452
4287	3	p	1.100	1.100	1.103	1.100	1.100	0.950	1.394	1.391
4413	2	p	0.900	1.050	1.155	1.143	1.155	0.900	1.135	1.123
4416	18	p	1.000	1.100	1.155	1.207	1.155	0.900	1.321	1.380
4417	8	g	1.000	1.100	1.155	1.207	1.210	0.900	1.384	1.446
4418	-1		0.900	1.100	1.097	1.086	1.155	0.900	1.129	1.118
4635	-1		1.050	1.100	1.050	1.100	1.100	0.900	1.201	1.258
4643	-1		1.050	1.050	1.050	1.103	1.050	0.900	1.094	1.149
4645	-1		1.100	1.100	1.103	1.095	1.155	0.900	1.387	1.377
4650	4	p	1.050	1.050	1.050	1.042	1.155	0.900	1.203	1.194
4654	-1		1.050	1.100	1.050	1.155	1.210	0.900	1.321	1.453

Table I.6 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	FactorE1	Factor F	Factor G	ESL	ESL+ extra
4724	14	p	1.000	1.100	1.155	1.207	1.155	0.900	1.321	1.380
4732	2	p	1.000	1.100	1.213	1.204	1.100	0.900	1.321	1.311
4735	-1		0.950	1.100	1.155	1.207	1.045	0.900	1.135	1.186
4738	-1		0.900	1.050	1.213	1.146	1.103	0.900	1.137	1.075
4739	-1		0.900	1.100	1.155	1.207	1.100	0.900	1.132	1.183
4801	2	p	1.100	0.950	1.103	1.091	1.000	0.900	1.037	1.027
4802	3	p	1.100	0.950	1.103	1.091	1.000	0.900	1.037	1.027
4803	9	g	1.100	1.100	1.158	1.210	1.100	0.950	1.464	1.530
4921	5	p	1.050	1.050	1.158	1.337	1.103	0.900	1.266	1.463
4925	-1		1.050	1.100	1.158	1.270	1.100	0.900	1.324	1.452
4933	-1		1.100	1.050	1.213	1.267	1.100	0.900	1.387	1.449
4940	1	g	1.100	1.050	1.158	1.337	1.050	0.900	1.264	1.459
6155	9	p	1.100	0.950	1.158	1.270	1.050	1.000	1.270	1.394
6159	3	p	1.100	1.100	1.158	1.337	1.045	0.900	1.317	1.522
6160	2	p	1.100	1.000	1.158	1.210	1.103	0.950	1.334	1.394
6161	-1		1.100	1.100	1.158	1.210	1.100	0.900	1.387	1.449
6168	3	p	1.050	1.000	1.158	1.337	0.998	1.000	1.212	1.400
6172	9	p	1.050	1.050	1.158	1.270	1.155	1.000	1.474	1.617
6173	4	g	1.050	1.100	1.158	1.337	1.155	0.900	1.390	1.605
6174	4	g	1.050	1.050	1.158	1.210	1.000	1.000	1.276	1.334
6176	4	g	1.050	1.100	1.158	1.210	1.210	1.000	1.618	1.691
6220	33	g	0.998	1.100	1.103	1.100	1.100	1.000	1.331	1.327
6225	20	p	1.050	1.100	1.158	1.155	1.100	0.950	1.397	1.394
6313	9	p	1.100	1.100	0.898	0.800	0.990	0.900	0.968	0.862
6321	1	p	1.050	0.950	0.898	0.896	0.950	1.050	0.893	0.891
6322	-1		1.050	1.100	0.855	0.768	1.045	0.950	0.980	0.880
6335	5	g	0.998	1.050	0.903	0.857	1.050	0.900	0.893	0.849
6339	13	p	1.050	1.100	0.855	0.810	0.998	0.950	0.936	0.887
6341	5	p	1.000	1.050	0.855	0.853	0.990	0.950	0.844	0.842
6343	4	p	1.000	1.100	0.855	0.768	0.990	0.950	0.885	0.794
6350	7	p	1.050	1.050	0.855	0.898	1.050	1.050	1.039	1.091
6351	2	p	1.000	1.050	0.950	0.855	1.045	0.900	0.938	0.844
6363	5	p	1.050	1.050	0.903	0.857	1.100	0.900	0.985	0.936
6364	11	g	1.050	1.050	0.898	0.848	1.100	0.950	1.034	0.977
6367	6	g	1.000	1.100	0.855	0.853	1.050	0.900	0.889	0.887
6369	9	p	1.000	1.100	0.950	0.903	1.045	0.900	0.983	0.934
6371	-1		1.050	1.050	0.855	0.853	1.050	1.000	0.990	0.987
6372	2	g	1.050	1.100	0.855	0.768	1.045	1.000	1.032	0.926
6373	13	p	1.050	1.100	0.855	0.770	1.100	0.900	0.978	0.880
6374	-1		1.050	1.100	0.903	0.853	1.100	0.900	1.032	0.975
6375	20	p	1.050	1.100	0.855	0.898	1.050	0.900	0.933	0.980
6376	8	p	1.050	1.100	0.855	0.853	0.945	0.950	0.887	0.884
6377	14	g	1.100	1.100	0.950	0.948	0.998	0.900	1.032	1.029
6378	-1		1.000	1.100	0.855	0.768	1.100	1.000	1.035	0.929
6379	0	p	1.000	1.050	0.855	0.810	1.050	1.050	0.990	0.938
6380	-1		1.050	1.100	0.898	0.896	1.155	0.900	1.078	1.075
6517	8	p	1.050	1.100	0.998	1.042	1.100	0.950	1.204	1.258
6538	11	p	1.050	1.050	0.948	0.990	0.998	0.900	0.938	0.980
6555	5	g	1.050	1.100	0.948	0.990	1.050	0.900	1.034	1.081
6556	6	p	0.950	1.100	0.948	1.042	1.045	0.900	0.931	1.024
6559	1	p	1.050	1.000	0.948	0.945	1.050	0.950	0.993	0.990
6561	3	p	1.000	1.050	0.950	0.998	1.050	0.950	0.995	1.045
6563	1	p	1.050	1.050	0.948	0.990	0.998	0.900	0.938	0.980
6567	6	p	1.050	1.050	0.950	0.903	0.900	0.900	0.848	0.806
6570	3	g	1.000	1.050	0.948	0.990	0.945	0.900	0.846	0.884
6574	8	p	1.050	1.100	0.998	1.042	1.045	0.900	1.084	1.132
6577	28	p	1.050	1.100	0.898	0.990	1.045	0.950	1.029	1.135
6578	9	g	0.998	1.100	0.950	0.995	1.045	0.950	1.035	1.084
6580	13	p	1.050	1.100	0.950	1.045	1.155	0.900	1.141	1.255
6581	13	p	1.050	1.100	0.948	0.990	1.050	0.900	1.034	1.081
6585	2	p	1.050	1.000	0.948	1.042	0.950	1.000	0.945	1.040
6587	7	p	1.050	1.050	0.998	1.100	1.050	0.950	1.097	1.209

Table I.6 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	FactorE1	Factor F	Factor G	ESL	ESL+ extra
6588	3	p	1.050	1.100	0.948	0.941	1.100	0.900	1.084	1.076
6589	2	p	1.100	1.100	0.948	1.042	1.100	0.950	1.198	1.318
6806	-1		1.050	1.100	0.950	0.948	1.210	0.900	1.195	1.192
6807	12	p	1.050	1.100	0.993	1.037	1.100	0.900	1.135	1.186
6814	2	p	1.050	1.000	0.948	0.938	1.000	1.000	0.995	0.985
6816	-1		1.050	1.100	0.948	0.990	1.100	1.050	1.264	1.321
6817	-1		1.050	1.100	0.948	1.042	0.990	1.050	1.138	1.252
6819	-1		1.050	1.100	0.950	0.898	1.100	0.900	1.086	1.027
6820	-1		1.050	1.100	0.993	1.037	1.100	0.900	1.135	1.186
6918	-1		1.050	1.100	1.000	1.045	1.155	0.900	1.201	1.255
6951	-1		1.050	1.100	0.898	0.896	1.155	0.900	1.078	1.075
6954	2	g	1.050	1.050	1.158	1.273	1.050	0.900	1.206	1.327
6959	-1		1.050	1.100	0.903	0.853	1.210	0.900	1.135	1.073
8413	-1		1.050	1.100	1.000	1.045	1.155	0.900	1.201	1.255
8418	4	p	1.050	1.050	0.948	0.938	1.050	1.000	1.097	1.086
8419	1	p	1.050	1.100	0.950	0.898	1.100	0.900	1.086	1.027
8429	2	p	1.050	1.000	1.103	1.152	1.050	0.900	1.094	1.143
8431	-1		1.050	1.100	1.158	1.270	1.100	0.900	1.324	1.452
8437	-1		1.050	1.000	0.948	0.995	1.050	0.900	0.940	0.987
8438	-1		1.050	1.100	0.948	0.938	1.100	1.000	1.204	1.192
8439	-1		1.050	1.050	0.948	0.938	1.050	0.900	0.987	0.977
8444	-1		1.050	1.100	0.855	0.812	1.100	1.100	1.195	1.135
8446	-1		1.050	1.100	0.950	0.998	1.100	0.900	1.086	1.141
8447	-1		1.050	1.100	0.855	0.853	1.155	0.900	1.027	1.024
8454	-1		1.050	1.100	0.948	0.938	1.100	0.900	1.084	1.073
8469	1	p	1.050	0.950	1.000	1.100	0.998	1.050	1.045	1.149
8518	-1		1.050	1.100	0.950	0.998	1.100	0.900	1.086	1.141
8519	-1		1.050	1.100	0.898	0.990	1.155	0.900	1.078	1.188
8520	-1		1.000	1.100	0.948	0.896	1.100	0.900	1.032	0.975
8521	-1		1.050	1.100	0.948	1.042	1.155	1.050	1.327	1.460
8523	-1		0.950	1.100	0.941	0.934	1.155	0.900	1.022	1.014
8527	-1		1.050	1.100	0.998	0.943	1.210	0.900	1.255	1.186
8531	4	p	1.050	1.100	0.950	0.948	1.100	0.900	1.086	1.084
8537	8	p	1.050	1.050	0.950	0.993	1.050	0.950	1.045	1.092
8539	-1		1.050	1.100	1.040	1.029	1.155	0.900	1.248	1.236
8540	1	p	1.050	1.000	0.950	0.993	0.950	0.950	0.900	0.941
8545	-1		1.050	1.100	0.855	0.810	1.210	0.900	1.075	1.019
8550	1	g	1.050	1.050	1.103	1.273	1.103	0.900	1.206	1.393
8561	-1		0.900	1.100	1.040	1.201	1.100	0.900	1.019	1.177
8563	-1		0.900	1.100	1.040	1.141	1.210	0.900	1.121	1.230
8577	-1		1.050	1.100	1.000	1.100	1.155	0.900	1.201	1.321
8583	-1		0.900	1.100	1.155	1.207	1.210	0.900	1.245	1.301
8598	-1		1.050	1.100	1.158	1.203	1.100	0.900	1.324	1.376
8913	2	p	1.050	1.050	1.050	0.992	1.050	0.900	1.094	1.034
8916	1	g	1.100	1.050	1.000	0.990	1.103	0.900	1.146	1.135
8918	-1		1.050	1.100	1.158	1.146	1.100	0.900	1.324	1.310
8919	-1		1.050	1.100	1.000	1.045	1.155	0.950	1.267	1.324
8922	10	p	1.050	1.100	1.050	1.155	1.045	0.950	1.204	1.324
8924	7	p	1.050	1.050	1.000	1.045	1.050	0.900	1.042	1.089
8926	-1		1.050	1.100	0.855	0.898	1.100	0.900	0.978	1.027
8929	5	p	1.050	1.050	0.898	0.990	1.100	0.950	1.034	1.140
8931	12	p	1.050	1.100	1.158	1.155	1.100	0.950	1.397	1.394
8941	-1		1.000	1.100	1.155	1.207	1.155	0.900	1.321	1.380
8951	-1		1.050	1.100	0.948	0.990	1.155	0.950	1.201	1.255
8955	-1		1.050	1.100	1.103	1.146	1.155	0.900	1.324	1.376
8964	-1		0.950	1.100	1.097	1.086	1.155	0.900	1.192	1.180
8966	-1		0.900	1.100	1.213	1.204	1.210	0.900	1.307	1.298
8976	-1		1.050	1.100	0.948	0.990	1.155	0.900	1.138	1.189
8984	-1		1.050	1.100	1.050	1.097	0.990	0.900	1.081	1.129
8994	7	p	1.050	1.100	1.050	1.091	1.045	0.900	1.141	1.186
8996	-1		1.050	1.100	1.158	1.337	1.210	0.900	1.456	1.682
8998	-1		1.000	1.100	1.040	0.884	1.155	0.900	1.189	1.011

Table I.7 ESL Derived from Factor Classes (averaged sub-factors) and Arbitrary Coding

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
164	5	g	5.000	5.000	5.000	5.333	4.000	1.000	500.000	533.333
170	-1		5.667	9.000	4.333	4.333	7.000	1.000	1547.000	1547.000
172	13	p	5.000	9.000	5.000	5.333	6.000	1.000	1350.000	1440.000
201	-1		5.667	9.000	3.000	3.667	7.000	3.000	3213.000	3927.000
374	12	p	5.667	9.000	4.333	4.667	7.000	1.000	1547.000	1666.000
375	9	p	5.667	7.000	4.333	4.667	5.000	3.000	2578.333	2776.667
376	-1		5.667	9.000	4.333	4.667	7.000	1.000	1547.000	1666.000
378	-1		5.667	9.000	4.333	4.667	7.000	1.000	1547.000	1666.000
379	6	g	5.667	9.000	4.333	5.000	7.000	1.000	1547.000	1785.000
380	-1		5.667	9.000	4.333	4.333	7.000	1.000	1547.000	1547.000
513	3	p	5.667	7.000	4.333	5.000	6.000	5.000	5156.667	5950.000
516	-1		5.667	9.000	3.667	5.000	7.000	5.000	6545.000	8925.000
518	4	p	5.667	7.000	4.333	4.333	7.000	1.000	1203.222	1203.222
735	1	p	5.667	1.000	5.000	5.667	3.000	1.000	85.000	96.333
740	27	g	5.667	9.000	5.000	5.667	7.000	1.000	1785.000	2023.000
742	2	g	6.333	5.000	5.000	5.333	4.000	1.000	633.333	675.556
743	1	p	5.667	5.000	5.000	5.333	6.000	7.000	5950.000	6346.667
744	10	p	5.667	7.000	5.000	5.333	7.000	1.000	1388.333	1480.889
745	6	p	5.667	9.000	5.000	5.000	7.000	3.000	5355.000	5355.000
805	23	g	6.333	9.000	5.000	5.333	6.000	1.000	1710.000	1824.000
808	4	p	5.667	7.000	4.333	4.667	5.000	3.000	2578.333	2776.667
809	12	g	5.667	9.000	5.000	5.333	6.000	1.000	1530.000	1632.000
810	-1		5.667	9.000	5.000	5.333	7.000	3.000	5355.000	5712.000
812	11	p	5.667	9.000	5.000	5.667	7.000	1.000	1785.000	2023.000
816	2	p	5.667	7.000	4.333	5.000	6.000	3.000	3094.000	3570.000
817	-1		5.667	9.000	4.333	4.667	7.000	1.000	1547.000	1666.000
888	14	p	5.667	9.000	5.000	5.333	7.000	1.000	1785.000	1904.000
963	-1		6.333	9.000	5.667	5.667	7.000	7.000	15827.000	15827.000
965	-1		5.667	9.000	5.667	5.667	8.000	3.000	6936.000	6936.000
984	13	p	6.333	9.000	5.667	6.333	5.000	3.000	4845.000	5415.000
1126	1	g	6.333	5.000	5.000	5.333	7.000	1.000	1108.333	1182.222
1129	1	p	5.667	9.000	5.000	5.333	7.000	1.000	1785.000	1904.000
1130	13	p	5.667	9.000	5.000	5.333	7.000	1.000	1785.000	1904.000
1262	26	g	5.667	9.000	7.000	6.333	8.000	5.000	14280.000	12920.000
1282	14	p	5.667	9.000	6.333	5.667	8.000	3.000	7752.000	6936.000
1405	4	g	5.667	7.000	5.000	5.333	7.000	1.000	1388.333	1480.889
1406	2	p	5.667	9.000	5.000	5.333	7.000	1.000	1785.000	1904.000
1407	5	p	5.667	7.000	4.333	5.333	6.000	3.000	3094.000	3808.000
1409	6	p	5.667	9.000	5.667	6.000	7.000	1.000	2023.000	2142.000
1410	3	g	5.667	7.000	5.667	5.667	5.000	1.000	1123.889	1123.889
1538	2	p	5.000	7.000	6.333	4.000	7.000	5.000	7758.333	4900.000
1540	11	p	4.333	9.000	7.000	4.667	6.000	5.000	8190.000	5460.000
1544	-1		4.333	9.000	7.000	5.000	7.000	1.000	1911.000	1365.000
1608	2	p	6.333	9.000	6.333	6.000	8.000	3.000	8664.000	8208.000
1754	19	p	5.667	9.000	5.000	5.667	6.000	1.000	1530.000	1734.000
1764	-1		5.667	9.000	5.000	5.667	6.000	1.000	1530.000	1734.000
1770	-1		5.667	9.000	3.667	4.333	8.000	1.000	1496.000	1768.000
1809	1	p	4.333	9.000	7.000	6.667	7.000	1.000	1911.000	1820.000
1810	-1		3.667	9.000	7.667	6.667	9.000	1.000	2277.000	1980.000
1943	-1		5.667	9.000	7.000	6.667	7.000	1.000	2499.000	2380.000
1948	2	p	5.667	7.000	7.000	6.667	7.000	1.000	1943.667	1851.111
1955	12	p	5.000	9.000	7.000	6.333	6.000	1.000	1890.000	1710.000
1956	3	p	5.667	9.000	7.000	6.667	7.000	1.000	2499.000	2380.000
1961	25	g	5.667	9.000	7.000	6.333	6.000	1.000	2142.000	1938.000
1967	1	p	6.333	7.000	6.333	6.333	7.000	1.000	1965.444	1965.444
1976	-1		5.667	9.000	7.000	6.333	6.000	1.000	2142.000	1938.000
1978	11	p	6.333	9.000	7.000	6.667	7.000	1.000	2793.000	2660.000
1979	3	p	6.333	7.000	5.000	5.000	6.000	1.000	1330.000	1330.000
1980	3	p	5.667	7.000	7.000	6.333	7.000	1.000	1943.667	1758.556
1982	-1		5.667	9.000	7.000	6.333	7.000	1.000	2499.000	2261.000
1983	12	p	6.333	9.000	7.000	6.333	6.000	1.000	2394.000	2166.000
1987	10	p	6.333	7.000	7.000	7.000	6.000	1.000	1862.000	1862.000
1989	15	p	5.667	9.000	7.000	7.000	6.000	1.000	2142.000	2142.000
2011	-1		5.667	9.000	7.000	6.333	6.000	1.000	2142.000	1938.000

Table I.7 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
2012	31	g	3.667	9.000	7.000	6.333	7.000	1.000	1617.000	1463.000
2014	16	p	4.333	9.000	7.000	6.333	7.000	1.000	1911.000	1729.000
2017	-1		5.667	9.000	7.000	6.000	7.000	1.000	2499.000	2142.000
2018	8	p	5.667	9.000	7.000	6.667	6.000	1.000	2142.000	2040.000
2019	24	p	5.667	9.000	7.000	6.667	7.000	1.000	2499.000	2380.000
2021	13	p	6.333	9.000	5.667	6.333	6.000	3.000	5814.000	6498.000
2023	12	g	6.333	9.000	7.000	6.667	4.000	1.000	1596.000	1520.000
2025	2	p	6.333	5.000	5.667	6.000	5.000	1.000	897.222	950.000
2026	22	p	6.333	9.000	7.000	6.667	7.000	1.000	2793.000	2660.000
2030	12	g	6.333	9.000	7.000	6.667	7.000	1.000	2793.000	2660.000
2032	-1		6.333	9.000	7.000	6.667	8.000	1.000	3192.000	3040.000
2033	12	p	6.333	9.000	7.000	7.000	6.000	1.000	2394.000	2394.000
2108	1	p	6.333	7.000	7.000	6.333	6.000	1.000	1862.000	1684.667
2111	5	p	6.333	1.000	7.000	6.333	3.000	1.000	133.000	120.333
2113	4	p	5.667	3.000	7.000	6.333	3.000	7.000	2499.000	2261.000
2211	5	g	6.333	7.000	5.667	5.667	5.000	1.000	1256.111	1256.111
2214	5	p	5.667	7.000	5.667	6.000	7.000	1.000	1573.444	1666.000
2216	13	p	5.667	9.000	5.667	6.000	7.000	1.000	2023.000	2142.000
2217	0	p	6.333	7.000	5.667	5.667	6.000	1.000	1507.333	1507.333
2218	11	p	6.333	9.000	5.667	6.000	6.000	1.000	1938.000	2052.000
2219	3	g	5.667	9.000	5.667	5.000	7.000	1.000	2023.000	1785.000
2220	-1		5.667	9.000	5.667	5.667	6.000	1.000	1734.000	1734.000
2310	4	p	6.333	9.000	5.667	6.000	7.000	1.000	2261.000	2394.000
2314	6	p	6.333	9.000	5.000	5.333	5.000	1.000	1425.000	1520.000
2316	6	p	5.667	9.000	5.667	5.667	6.000	1.000	1734.000	1734.000
2317	2	g	6.333	1.000	5.667	5.333	3.000	3.000	323.000	304.000
2323	3	p	5.667	3.000	6.333	6.333	4.000	1.000	430.667	430.667
2407	14	p	5.667	9.000	5.667	6.000	6.000	3.000	5202.000	5508.000
2409	-1		6.333	9.000	6.333	6.000	6.000	3.000	6498.000	6156.000
2410	2	p	6.333	7.000	6.333	6.000	6.000	3.000	5054.000	4788.000
2510	-1		5.667	9.000	6.333	6.000	6.000	1.000	1938.000	1836.000
2609	-1		5.667	9.000	6.333	6.000	6.000	3.000	5814.000	5508.000
2613	2	p	5.667	5.000	6.333	5.333	6.000	1.000	1076.667	906.667
2615	3	p	5.667	7.000	6.333	6.000	4.000	3.000	3014.667	2856.000
2747	-1		5.667	9.000	7.000	6.667	6.000	1.000	2142.000	2040.000
2764	12	p	5.000	9.000	7.000	6.667	6.000	1.000	1890.000	1800.000
2766	1	g	5.667	9.000	7.000	6.667	6.000	1.000	2142.000	2040.000
2767	14	p	5.000	9.000	7.000	6.667	4.000	1.000	1260.000	1200.000
2768	12	p	5.667	7.000	7.000	7.000	6.000	1.000	1666.000	1666.000
2769	8	p	5.000	5.000	8.333	6.667	5.000	1.000	1041.667	833.333
2770	2	p	6.333	5.000	7.000	6.333	6.000	1.000	1330.000	1203.333
2772	3	p	6.333	9.000	7.000	6.667	5.000	1.000	1995.000	1900.000
2773	4	p	6.333	9.000	7.000	6.667	5.000	1.000	1995.000	1900.000
2775	2	p	6.333	7.000	7.667	7.000	6.000	1.000	2039.333	1862.000
2776	3	p	5.667	5.000	7.000	7.000	5.000	1.000	991.667	991.667
2779	3	p	5.667	5.000	7.000	6.000	5.000	1.000	991.667	850.000
2780	7	g	5.667	9.000	7.000	7.000	7.000	1.000	2499.000	2499.000
2782	-1		5.667	9.000	8.333	6.667	7.000	1.000	2975.000	2380.000
2832	3	g	5.667	9.000	7.667	6.667	6.000	1.000	2346.000	2040.000
2833	10	g	5.667	7.000	7.000	7.000	6.000	3.000	4998.000	4998.000
2834	14	p	6.333	9.000	7.667	6.667	6.000	1.000	2622.000	2280.000
2841	4	p	5.667	9.000	7.000	6.333	7.000	1.000	2499.000	2261.000
2842	2	p	5.667	9.000	7.667	7.000	7.000	1.000	2737.000	2499.000
2909	3	p	5.667	7.000	4.333	5.333	7.000	1.000	1203.222	1480.889
2910	7	g	5.667	7.000	3.667	3.667	6.000	3.000	2618.000	2618.000
2912	-1		5.667	9.000	4.333	5.000	8.000	3.000	5304.000	6120.000
2914	4	g	5.667	7.000	5.000	5.333	6.000	3.000	3570.000	3808.000
3024	11	p	6.333	9.000	5.667	6.000	6.000	1.000	1938.000	2052.000
3027	5	g	6.333	5.000	5.667	5.667	5.000	1.000	897.222	897.222
3029	8	p	5.667	7.000	5.667	6.000	6.000	1.000	1348.667	1428.000
3032	-1		5.667	9.000	5.667	6.000	8.000	1.000	2312.000	2448.000
3033	-1		6.333	9.000	5.000	5.333	8.000	1.000	2280.000	2432.000
3034	-1		5.667	9.000	5.667	6.000	7.000	1.000	2023.000	2142.000
3106	-1		5.000	9.000	8.333	6.333	8.000	1.000	3000.000	2280.000

Table I.7 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
3203	12	p	5.000	9.000	6.333	6.333	5.000	3.000	4275.000	4275.000
3208	2	g	6.333	5.000	7.000	6.667	6.000	1.000	1330.000	1266.667
3210	-1		4.333	9.000	7.000	6.000	9.000	1.000	2457.000	2106.000
3403	3	p	6.333	7.000	7.000	6.000	5.000	5.000	7758.333	6650.000
3408	-1		5.667	9.000	7.000	5.333	9.000	1.000	3213.000	2448.000
3487	5	p	5.667	9.000	7.000	6.333	7.000	5.000	12495.000	11305.000
3488	1	p	5.667	5.000	7.000	5.333	4.000	3.000	2380.000	1813.333
3514	-1		5.000	9.000	5.000	4.667	8.000	1.000	1800.000	1680.000
3515	10	g	4.333	7.000	4.333	4.667	7.000	1.000	920.111	990.889
3516	1	p	5.667	7.000	5.667	4.000	7.000	1.000	1573.444	1110.667
3517	-1		5.000	9.000	5.000	4.000	7.000	1.000	1575.000	1260.000
3627	-1		5.667	9.000	5.667	5.667	8.000	1.000	2312.000	2312.000
3641	14	p	5.000	9.000	5.667	6.000	7.000	1.000	1785.000	1890.000
3646	-1		5.667	9.000	5.667	5.667	8.000	1.000	2312.000	2312.000
3651	2	g	5.667	5.000	5.667	5.667	5.000	1.000	802.778	802.778
3652	2	p	5.667	7.000	5.667	5.333	7.000	1.000	1573.444	1480.889
3654	2	p	5.667	7.000	5.667	5.333	6.000	3.000	4046.000	3808.000
3655	12	p	5.667	9.000	4.333	4.333	7.000	1.000	1547.000	1547.000
3825	5	p	6.333	7.000	7.000	6.333	7.000	1.000	2172.333	1965.444
3835	8	p	4.333	9.000	7.000	6.667	6.000	1.000	1638.000	1560.000
3864	11	p	5.667	9.000	7.000	7.000	7.000	1.000	2499.000	2499.000
3865	12	p	5.667	9.000	7.000	6.333	4.000	1.000	1428.000	1292.000
3866	2	g	6.333	5.000	7.000	7.000	2.000	3.000	1330.000	1330.000
3867	23	p	5.667	9.000	7.000	7.000	7.000	1.000	2499.000	2499.000
3868	8	p	6.333	7.000	6.333	6.333	6.000	1.000	1684.667	1684.667
3872	6	p	5.000	7.000	7.000	6.333	6.000	1.000	1470.000	1330.000
3874	10	g	6.333	9.000	7.000	6.667	5.000	1.000	1995.000	1900.000
3875	-1		5.667	9.000	7.000	6.667	7.000	1.000	2499.000	2380.000
3882	-1		5.667	9.000	7.000	6.667	7.000	1.000	2499.000	2380.000
3911	-1		5.000	9.000	5.000	5.333	6.000	1.000	1350.000	1440.000
3913	5	p	5.667	7.000	5.667	5.667	6.000	3.000	4046.000	4046.000
3914	2	g	5.667	9.000	4.333	4.667	6.000	1.000	1326.000	1428.000
3915	-1		5.667	9.000	5.667	6.000	6.000	3.000	5202.000	5508.000
4025	-1		4.333	9.000	7.000	6.667	8.000	1.000	2184.000	2080.000
4026	-1		3.667	9.000	7.667	6.667	9.000	1.000	2277.000	1980.000
4149	3	p	5.667	5.000	7.000	6.667	6.000	1.000	1190.000	1133.333
4152	19	p	4.333	9.000	7.000	6.667	5.000	3.000	4095.000	3900.000
4158	12	p	6.333	9.000	7.000	6.667	7.000	1.000	2793.000	2660.000
4159	21	p	5.000	9.000	7.000	6.667	6.000	1.000	1890.000	1800.000
4162	18	p	6.333	9.000	7.000	6.667	6.000	3.000	7182.000	6840.000
4166	-1		5.667	9.000	6.333	6.000	7.000	5.000	11305.000	10710.000
4169	2	p	5.667	5.000	7.000	6.333	5.000	5.000	4958.333	4486.111
4171	2	g	6.333	7.000	7.000	6.000	6.000	5.000	9310.000	7980.000
4172	-1		5.667	9.000	7.000	7.000	6.000	5.000	10710.000	10710.000
4173	-1		6.333	9.000	7.000	6.333	8.000	5.000	15960.000	14440.000
4178	3	p	5.667	7.000	7.000	6.667	7.000	1.000	1943.667	1851.111
4279	-1		5.667	9.000	6.333	6.000	9.000	1.000	2907.000	2754.000
4286	4	p	6.333	9.000	6.333	5.667	8.000	3.000	8664.000	7752.000
4287	3	p	6.333	9.000	6.333	5.667	7.000	3.000	7581.000	6783.000
4413	2	p	3.667	7.000	7.000	6.000	8.000	1.000	1437.333	1232.000
4416	18	p	5.000	9.000	7.000	6.333	8.000	1.000	2520.000	2280.000
4417	8	g	5.000	9.000	7.000	6.333	9.000	1.000	2835.000	2565.000
4418	-1		3.667	9.000	6.333	5.667	8.000	1.000	1672.000	1496.000
4635	-1		5.667	9.000	5.667	5.667	7.000	1.000	2023.000	2023.000
4643	-1		5.667	7.000	5.667	5.667	6.000	1.000	1348.667	1348.667
4645	-1		6.333	9.000	6.333	5.667	8.000	1.000	2888.000	2584.000
4650	4	p	5.667	7.000	5.667	5.333	8.000	1.000	1798.222	1692.444
4654	-1		5.667	9.000	5.667	6.000	9.000	1.000	2601.000	2754.000
4724	14	p	5.000	9.000	7.000	6.333	8.000	1.000	2520.000	2280.000
4732	2	p	5.000	9.000	7.667	6.333	7.000	1.000	2415.000	1995.000
4735	-1		4.333	9.000	7.000	6.333	6.000	1.000	1638.000	1482.000
4738	-1		3.667	7.000	7.667	6.000	7.000	1.000	1377.444	1078.000
4739	-1		3.667	9.000	7.000	6.333	7.000	1.000	1617.000	1463.000
4801	2	p	6.333	3.000	6.333	5.667	5.000	1.000	601.667	538.333

Table I.7 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
4802	3	p	6.333	3.000	6.333	5.667	5.000	1.000	601.667	538.333
4803	9	g	6.333	9.000	7.000	6.333	7.000	3.000	8379.000	7581.000
4921	5	p	5.667	7.000	7.000	7.000	7.000	1.000	1943.667	1943.667
4925	-1		5.667	9.000	7.000	6.667	7.000	1.000	2499.000	2380.000
4933	-1		6.333	7.000	7.667	6.667	7.000	1.000	2379.222	2068.889
4940	1	g	6.333	7.000	7.000	7.000	6.000	1.000	1862.000	1862.000
6155	9	p	6.333	3.000	7.000	6.667	6.000	5.000	3990.000	3800.000
6159	3	p	6.333	9.000	7.000	7.000	6.000	1.000	2394.000	2394.000
6160	2	p	6.333	5.000	7.000	6.333	7.000	3.000	4655.000	4211.667
6161	-1		6.333	9.000	7.000	6.333	7.000	1.000	2793.000	2527.000
6168	3	p	5.667	5.000	7.000	7.000	5.000	5.000	4958.333	4958.333
6172	9	p	5.667	7.000	7.000	6.667	8.000	5.000	11106.667	10577.778
6173	4	g	5.667	9.000	7.000	7.000	8.000	1.000	2856.000	2856.000
6174	4	g	5.667	7.000	7.000	6.333	5.000	5.000	6941.667	6280.556
6176	4	g	5.667	9.000	7.000	6.333	9.000	5.000	16065.000	14535.000
6220	33	g	5.000	9.000	6.333	5.667	7.000	5.000	9975.000	8925.000
6225	20	p	5.667	9.000	7.000	6.000	7.000	3.000	7497.000	6426.000
6313	9	p	6.333	9.000	3.667	3.667	5.000	1.000	1045.000	1045.000
6321	1	p	5.667	3.000	3.667	4.333	4.000	7.000	1745.333	2062.667
6322	-1		5.667	9.000	3.000	3.333	6.000	3.000	2754.000	3060.000
6335	5	g	5.000	7.000	3.667	4.000	6.000	1.000	770.000	840.000
6339	13	p	5.667	9.000	3.000	3.667	5.000	3.000	2295.000	2805.000
6341	5	p	5.000	7.000	3.000	4.000	5.000	3.000	1575.000	2100.000
6343	4	p	5.000	9.000	3.000	3.333	5.000	3.000	2025.000	2250.000
6350	7	p	5.667	7.000	3.000	4.333	6.000	7.000	4998.000	7219.333
6351	2	p	5.000	7.000	4.333	4.000	6.000	1.000	910.000	840.000
6363	5	p	5.667	7.000	3.667	4.000	7.000	1.000	1018.111	1110.667
6364	11	g	5.667	7.000	3.667	4.000	7.000	3.000	3054.333	3332.000
6367	6	g	5.000	9.000	3.000	4.000	6.000	1.000	810.000	1080.000
6369	9	p	5.000	9.000	4.333	4.333	6.000	1.000	1170.000	1170.000
6371	-1		5.667	7.000	3.000	4.000	6.000	5.000	3570.000	4760.000
6372	2	g	5.667	9.000	3.000	3.333	6.000	5.000	4590.000	5100.000
6373	13	p	5.667	9.000	3.000	3.333	7.000	1.000	1071.000	1190.000
6374	-1		5.667	9.000	3.667	4.000	7.000	1.000	1309.000	1428.000
6375	20	p	5.667	9.000	3.000	4.333	6.000	1.000	918.000	1326.000
6376	8	p	5.667	9.000	3.000	4.000	4.000	3.000	1836.000	2448.000
6377	14	g	6.333	9.000	4.333	4.667	5.000	1.000	1235.000	1330.000
6378	-1		5.000	9.000	3.000	3.333	7.000	5.000	4725.000	5250.000
6379	0	p	5.000	7.000	3.000	3.667	6.000	7.000	4410.000	5390.000
6380	-1		5.667	9.000	3.667	4.333	8.000	1.000	1496.000	1768.000
6517	8	p	5.667	9.000	5.000	5.333	7.000	3.000	5355.000	5712.000
6538	11	p	5.667	7.000	4.333	5.000	5.000	1.000	859.444	991.667
6555	5	g	5.667	9.000	4.333	5.000	6.000	1.000	1326.000	1530.000
6556	6	p	4.333	9.000	4.333	5.333	6.000	1.000	1014.000	1248.000
6559	1	p	5.667	5.000	4.333	4.667	6.000	3.000	2210.000	2380.000
6561	3	p	5.000	7.000	4.333	5.000	6.000	3.000	2730.000	3150.000
6563	1	p	5.667	7.000	4.333	5.000	5.000	1.000	859.444	991.667
6567	6	p	5.667	7.000	4.333	4.333	3.000	1.000	515.667	515.667
6570	3	g	5.000	7.000	4.333	5.000	4.000	1.000	606.667	700.000
6574	8	p	5.667	9.000	5.000	5.333	6.000	1.000	1530.000	1632.000
6577	28	p	5.667	9.000	3.667	5.000	6.000	3.000	3366.000	4590.000
6578	9	g	5.000	9.000	4.333	5.000	6.000	3.000	3510.000	4050.000
6580	13	p	5.667	9.000	4.333	5.333	8.000	1.000	1768.000	2176.000
6581	13	p	5.667	9.000	4.333	5.000	6.000	1.000	1326.000	1530.000
6585	2	p	5.667	5.000	4.333	5.333	4.000	5.000	2455.556	3022.222
6587	7	p	5.667	7.000	5.000	5.667	6.000	3.000	3570.000	4046.000
6588	3	p	5.667	9.000	4.333	4.667	7.000	1.000	1547.000	1666.000
6589	2	p	6.333	9.000	4.333	5.333	7.000	3.000	5187.000	6384.000
6806	-1		5.667	9.000	4.333	4.667	9.000	1.000	1989.000	2142.000
6807	12	p	5.667	9.000	5.000	5.333	7.000	1.000	1785.000	1904.000
6814	2	p	5.667	5.000	4.333	4.667	5.000	5.000	3069.444	3305.556
6816	-1		5.667	9.000	4.333	5.000	7.000	7.000	10829.000	12495.000
6817	-1		5.667	9.000	4.333	5.333	5.000	7.000	7735.000	9520.000
6819	-1		5.667	9.000	4.333	4.333	7.000	1.000	1547.000	1547.000

Table I.7 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
6820	-1		5.667	9.000	5.000	5.333	7.000	1.000	1785.000	1904.000
6918	-1		5.667	9.000	5.000	5.333	8.000	1.000	2040.000	2176.000
6951	-1		5.667	9.000	3.667	4.333	8.000	1.000	1496.000	1768.000
6954	2	g	5.667	7.000	7.000	6.667	6.000	1.000	1666.000	1586.667
6959	-1		5.667	9.000	3.667	4.000	9.000	1.000	1683.000	1836.000
8413	-1		5.667	9.000	5.000	5.333	8.000	1.000	2040.000	2176.000
8418	4	p	5.667	7.000	4.333	4.667	6.000	5.000	5156.667	5553.333
8419	1	p	5.667	9.000	4.333	4.333	7.000	1.000	1547.000	1547.000
8429	2	p	5.667	5.000	6.333	6.000	6.000	1.000	1076.667	1020.000
8431	-1		5.667	9.000	7.000	6.667	7.000	1.000	2499.000	2380.000
8437	-1		5.667	5.000	4.333	5.000	6.000	1.000	736.667	850.000
8438	-1		5.667	9.000	4.333	4.667	7.000	5.000	7735.000	8330.000
8439	-1		5.667	7.000	4.333	4.667	6.000	1.000	1031.333	1110.667
8444	-1		5.667	9.000	3.000	3.667	7.000	9.000	9639.000	11781.000
8446	-1		5.667	9.000	4.333	5.000	7.000	1.000	1547.000	1785.000
8447	-1		5.667	9.000	3.000	4.000	8.000	1.000	1224.000	1632.000
8454	-1		5.667	9.000	4.333	4.667	7.000	1.000	1547.000	1666.000
8469	1	p	5.667	3.000	5.000	5.667	5.000	7.000	2975.000	3371.667
8518	-1		5.667	9.000	4.333	5.000	7.000	1.000	1547.000	1785.000
8519	-1		5.667	9.000	3.667	5.000	8.000	1.000	1496.000	2040.000
8520	-1		5.000	9.000	4.333	4.333	7.000	1.000	1365.000	1365.000
8521	-1		5.667	9.000	4.333	5.333	8.000	7.000	12376.000	15232.000
8523	-1		4.333	9.000	4.333	4.667	8.000	1.000	1352.000	1456.000
8527	-1		5.667	9.000	5.000	4.667	9.000	1.000	2295.000	2142.000
8531	4	p	5.667	9.000	4.333	4.667	7.000	1.000	1547.000	1666.000
8537	8	p	5.667	7.000	4.333	5.000	6.000	3.000	3094.000	3570.000
8539	-1		5.667	9.000	5.667	5.333	8.000	1.000	2312.000	2176.000
8540	1	p	5.667	5.000	4.333	5.000	4.000	3.000	1473.333	1700.000
8545	-1		5.667	9.000	3.000	3.667	9.000	1.000	1377.000	1683.000
8550	1	g	5.667	7.000	6.333	6.667	7.000	1.000	1758.556	1851.111
8561	-1		3.667	9.000	5.667	6.333	7.000	1.000	1309.000	1463.000
8563	-1		3.667	9.000	5.667	6.000	9.000	1.000	1683.000	1782.000
8577	-1		5.667	9.000	5.000	5.667	8.000	1.000	2040.000	2312.000
8583	-1		3.667	9.000	7.000	6.333	9.000	1.000	2079.000	1881.000
8598	-1		5.667	9.000	7.000	6.333	7.000	1.000	2499.000	2261.000
8913	2	p	5.667	7.000	5.667	5.000	6.000	1.000	1348.667	1190.000
8916	1	g	6.333	7.000	5.000	5.000	7.000	1.000	1551.667	1551.667
8918	-1		5.667	9.000	7.000	6.000	7.000	1.000	2499.000	2142.000
8919	-1		5.667	9.000	5.000	5.333	8.000	3.000	6120.000	6528.000
8922	10	p	5.667	9.000	5.667	6.000	6.000	3.000	5202.000	5508.000
8924	7	p	5.667	7.000	5.000	5.333	6.000	1.000	1190.000	1269.333
8926	-1		5.667	9.000	3.000	4.333	7.000	1.000	1071.000	1547.000
8929	5	p	5.667	7.000	3.667	5.000	7.000	3.000	3054.333	4165.000
8931	12	p	5.667	9.000	7.000	6.000	7.000	3.000	7497.000	6426.000
8941	-1		5.000	9.000	7.000	6.333	8.000	1.000	2520.000	2280.000
8951	-1		5.667	9.000	4.333	5.000	8.000	3.000	5304.000	6120.000
8955	-1		5.667	9.000	6.333	6.000	8.000	1.000	2584.000	2448.000
8964	-1		4.333	9.000	6.333	5.667	8.000	1.000	1976.000	1768.000
8966	-1		3.667	9.000	7.667	6.333	9.000	1.000	2277.000	1881.000
8976	-1		5.667	9.000	4.333	5.000	8.000	1.000	1768.000	2040.000
8984	-1		5.667	9.000	5.667	5.667	5.000	1.000	1445.000	1445.000
8994	7	p	5.667	9.000	5.667	5.667	6.000	1.000	1734.000	1734.000
8996	-1		5.667	9.000	7.000	7.000	9.000	1.000	3213.000	3213.000
8998	-1		5.000	9.000	5.667	4.333	8.000	1.000	2040.000	1560.000

Note: -1 represent no leaks

Table I.8 ESL Derived from Factor Classes (averaged sub-factors) and ISO Suggested Coding

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
164	5	g	1.000	1.000	1.000	1.008	0.975	0.900	0.878	0.885
170	-1		1.017	1.100	0.983	0.983	1.050	0.900	1.039	1.039
172	13	p	1.000	1.100	1.000	1.008	1.025	0.900	1.015	1.023
201	-1		1.017	1.100	0.950	0.967	1.050	0.950	1.060	1.078
374	12	p	1.017	1.100	0.983	0.992	1.050	0.900	1.039	1.048
375	9	p	1.017	1.050	0.983	0.992	1.000	0.950	0.997	1.006
376	-1		1.017	1.100	0.983	0.992	1.050	0.900	1.039	1.048
378	-1		1.017	1.100	0.983	0.992	1.050	0.900	1.039	1.048
379	6	g	1.017	1.100	0.983	1.000	1.050	0.900	1.039	1.057
380	-1		1.017	1.100	0.983	0.983	1.050	0.900	1.039	1.039
513	3	p	1.017	1.050	0.983	1.000	1.025	1.000	1.076	1.094
516	-1		1.017	1.100	0.967	1.000	1.050	1.000	1.135	1.174
518	4	p	1.017	1.050	0.983	0.983	1.050	0.900	0.992	0.992
735	1	p	1.017	0.900	1.000	1.017	0.950	0.900	0.782	0.795
740	27	g	1.017	1.100	1.000	1.017	1.050	0.900	1.057	1.074
742	2	g	1.033	1.000	1.000	1.008	0.975	0.900	0.907	0.914
743	1	p	1.017	1.000	1.000	1.008	1.025	1.050	1.094	1.103
744	10	p	1.017	1.050	1.000	1.008	1.050	0.900	1.009	1.017
745	6	p	1.017	1.100	1.000	1.000	1.050	0.950	1.116	1.116
805	23	g	1.033	1.100	1.000	1.008	1.025	0.900	1.049	1.057
808	4	p	1.017	1.050	0.983	0.992	1.000	0.950	0.997	1.006
809	12	g	1.017	1.100	1.000	1.008	1.025	0.900	1.032	1.040
810	-1		1.017	1.100	1.000	1.008	1.050	0.950	1.116	1.125
812	11	p	1.017	1.100	1.000	1.017	1.050	0.900	1.057	1.074
816	2	p	1.017	1.050	0.983	1.000	1.025	0.950	1.022	1.039
817	-1		1.017	1.100	0.983	0.992	1.050	0.900	1.039	1.048
888	14	p	1.017	1.100	1.000	1.008	1.050	0.900	1.057	1.066
963	-1		1.033	1.100	1.017	1.017	1.050	1.050	1.274	1.274
965	-1		1.017	1.100	1.017	1.017	1.075	0.950	1.161	1.161
984	13	p	1.033	1.100	1.017	1.033	1.000	0.950	1.098	1.116
1126	1	g	1.033	1.000	1.000	1.008	1.050	0.900	0.977	0.985
1129	1	p	1.017	1.100	1.000	1.008	1.050	0.900	1.057	1.066
1130	13	p	1.017	1.100	1.000	1.008	1.050	0.900	1.057	1.066
1262	26	g	1.017	1.100	1.050	1.033	1.075	1.000	1.262	1.242
1282	14	p	1.017	1.100	1.033	1.017	1.075	0.950	1.180	1.161
1405	4	g	1.017	1.050	1.000	1.008	1.050	0.900	1.009	1.017
1406	2	p	1.017	1.100	1.000	1.008	1.050	0.900	1.057	1.066
1407	5	p	1.017	1.050	0.983	1.008	1.025	0.950	1.022	1.048
1409	6	p	1.017	1.100	1.017	1.025	1.050	0.900	1.074	1.083
1410	3	g	1.017	1.050	1.017	1.017	1.000	0.900	0.977	0.977
1538	2	p	1.000	1.050	1.033	0.975	1.050	1.000	1.139	1.075
1540	11	p	0.983	1.100	1.050	0.992	1.025	1.000	1.164	1.099
1544	-1		0.983	1.100	1.050	1.000	1.050	0.900	1.073	1.022
1608	2	p	1.033	1.100	1.033	1.025	1.075	0.950	1.200	1.190
1754	19	p	1.017	1.100	1.000	1.017	1.025	0.900	1.032	1.049
1764	-1		1.017	1.100	1.000	1.017	1.025	0.900	1.032	1.049
1770	-1		1.017	1.100	0.967	0.983	1.075	0.900	1.046	1.064
1809	1	p	0.983	1.100	1.050	1.042	1.050	0.900	1.073	1.065
1810	-1		0.967	1.100	1.067	1.042	1.100	0.900	1.123	1.097
1943	-1		1.017	1.100	1.050	1.042	1.050	0.900	1.110	1.101
1948	2	p	1.017	1.050	1.050	1.042	1.050	0.900	1.059	1.051
1955	12	p	1.000	1.100	1.050	1.033	1.025	0.900	1.065	1.049
1956	3	p	1.017	1.100	1.050	1.042	1.050	0.900	1.110	1.101
1961	25	g	1.017	1.100	1.050	1.033	1.025	0.900	1.083	1.066
1967	1	p	1.033	1.050	1.033	1.033	1.050	0.900	1.060	1.060
1976	-1		1.017	1.100	1.050	1.033	1.025	0.900	1.083	1.066
1978	11	p	1.033	1.100	1.050	1.042	1.050	0.900	1.128	1.119
1979	3	p	1.033	1.050	1.000	1.000	1.025	0.900	1.001	1.001
1980	3	p	1.017	1.050	1.050	1.033	1.050	0.900	1.059	1.042
1982	-1		1.017	1.100	1.050	1.033	1.050	0.900	1.110	1.092
1983	12	p	1.033	1.100	1.050	1.033	1.025	0.900	1.101	1.084
1987	10	p	1.033	1.050	1.050	1.050	1.025	0.900	1.051	1.051
1989	15	p	1.017	1.100	1.050	1.050	1.025	0.900	1.083	1.083
2011	-1		1.017	1.100	1.050	1.033	1.025	0.900	1.083	1.066
2012	31	g	0.967	1.100	1.050	1.033	1.050	0.900	1.055	1.038
2014	16	p	0.983	1.100	1.050	1.033	1.050	0.900	1.073	1.056
2017	-1		1.017	1.100	1.050	1.025	1.050	0.900	1.110	1.083
2018	8	p	1.017	1.100	1.050	1.042	1.025	0.900	1.083	1.075

Table I.8 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
2019	24	p	1.017	1.100	1.050	1.042	1.050	0.900	1.110	1.101
2021	13	p	1.033	1.100	1.017	1.033	1.025	0.950	1.125	1.144
2023	12	g	1.033	1.100	1.050	1.042	0.975	0.900	1.047	1.039
2025	2	p	1.033	1.000	1.017	1.025	1.000	0.900	0.946	0.953
2026	22	p	1.033	1.100	1.050	1.042	1.050	0.900	1.128	1.119
2030	12	g	1.033	1.100	1.050	1.042	1.050	0.900	1.128	1.119
2032	-1		1.033	1.100	1.050	1.042	1.075	0.900	1.155	1.146
2033	12	p	1.033	1.100	1.050	1.050	1.025	0.900	1.101	1.101
2108	1	p	1.033	1.050	1.050	1.033	1.025	0.900	1.051	1.034
2111	5	p	1.033	0.900	1.050	1.033	0.950	0.900	0.835	0.822
2113	4	p	1.017	0.950	1.050	1.033	0.950	1.050	1.012	0.996
2211	5	g	1.033	1.050	1.017	1.017	1.000	0.900	0.993	0.993
2214	5	p	1.017	1.050	1.017	1.025	1.050	0.900	1.026	1.034
2216	13	p	1.017	1.100	1.017	1.025	1.050	0.900	1.074	1.083
2217	0	p	1.033	1.050	1.017	1.017	1.025	0.900	1.018	1.018
2218	11	p	1.033	1.100	1.017	1.025	1.025	0.900	1.066	1.075
2219	3	g	1.017	1.100	1.017	1.000	1.050	0.900	1.074	1.057
2220	-1		1.017	1.100	1.017	1.017	1.025	0.900	1.049	1.049
2310	4	p	1.033	1.100	1.017	1.025	1.050	0.900	1.092	1.101
2314	6	p	1.033	1.100	1.000	1.008	1.000	0.900	1.023	1.032
2316	6	p	1.017	1.100	1.017	1.017	1.025	0.900	1.049	1.049
2317	2	g	1.033	0.900	1.017	1.008	0.950	0.950	0.853	0.846
2323	3	p	1.017	0.950	1.033	1.033	0.975	0.900	0.876	0.876
2407	14	p	1.017	1.100	1.017	1.025	1.025	0.950	1.107	1.116
2409	-1		1.033	1.100	1.033	1.025	1.025	0.950	1.144	1.134
2410	2	p	1.033	1.050	1.033	1.025	1.025	0.950	1.092	1.083
2510	-1		1.017	1.100	1.033	1.025	1.025	0.900	1.066	1.057
2609	-1		1.017	1.100	1.033	1.025	1.025	0.950	1.125	1.116
2613	2	p	1.017	1.000	1.033	1.008	1.025	0.900	0.969	0.946
2615	3	p	1.017	1.050	1.033	1.025	0.975	0.950	1.022	1.013
2747	-1		1.017	1.100	1.050	1.042	1.025	0.900	1.083	1.075
2764	12	p	1.000	1.100	1.050	1.042	1.025	0.900	1.065	1.057
2766	1	g	1.017	1.100	1.050	1.042	1.025	0.900	1.083	1.075
2767	14	p	1.000	1.100	1.050	1.042	0.975	0.900	1.014	1.005
2768	12	p	1.017	1.050	1.050	1.050	1.025	0.900	1.034	1.034
2769	8	p	1.000	1.000	1.083	1.042	1.000	0.900	0.975	0.938
2770	2	p	1.033	1.000	1.050	1.033	1.025	0.900	1.001	0.985
2772	3	p	1.033	1.100	1.050	1.042	1.000	0.900	1.074	1.066
2773	4	p	1.033	1.100	1.050	1.042	1.000	0.900	1.074	1.066
2775	2	p	1.033	1.050	1.067	1.050	1.025	0.900	1.068	1.051
2776	3	p	1.017	1.000	1.050	1.050	1.000	0.900	0.961	0.961
2779	3	p	1.017	1.000	1.050	1.025	1.000	0.900	0.961	0.938
2780	7	g	1.017	1.100	1.050	1.050	1.050	0.900	1.110	1.110
2782	-1		1.017	1.100	1.083	1.042	1.050	0.900	1.145	1.101
2832	3	g	1.017	1.100	1.067	1.042	1.025	0.900	1.100	1.075
2833	10	g	1.017	1.050	1.050	1.050	1.025	0.950	1.091	1.091
2834	14	p	1.033	1.100	1.067	1.042	1.025	0.900	1.118	1.092
2841	4	p	1.017	1.100	1.050	1.033	1.050	0.900	1.110	1.092
2842	2	p	1.017	1.100	1.067	1.050	1.050	0.900	1.127	1.110
2909	3	p	1.017	1.050	0.983	1.008	1.050	0.900	0.992	1.017
2910	7	g	1.017	1.050	0.967	0.967	1.025	0.950	1.005	1.005
2912	-1		1.017	1.100	0.983	1.000	1.075	0.950	1.123	1.142
2914	4	g	1.017	1.050	1.000	1.008	1.025	0.950	1.039	1.048
3024	11	p	1.033	1.100	1.017	1.025	1.025	0.900	1.066	1.075
3027	5	g	1.033	1.000	1.017	1.017	1.000	0.900	0.946	0.946
3029	8	p	1.017	1.050	1.017	1.025	1.025	0.900	1.001	1.009
3032	-1		1.017	1.100	1.017	1.025	1.075	0.900	1.100	1.109
3033	-1		1.033	1.100	1.000	1.008	1.075	0.900	1.100	1.109
3034	-1		1.017	1.100	1.017	1.025	1.050	0.900	1.074	1.083
3106	-1		1.000	1.100	1.083	1.033	1.075	0.900	1.153	1.100
3203	12	p	1.000	1.100	1.033	1.033	1.000	0.950	1.080	1.080
3208	2	g	1.033	1.000	1.050	1.042	1.025	0.900	1.001	0.993
3210	-1		0.983	1.100	1.050	1.025	1.100	0.900	1.124	1.098
3403	3	p	1.033	1.050	1.050	1.025	1.000	1.000	1.139	1.112
3408	-1		1.017	1.100	1.050	1.008	1.100	0.900	1.163	1.116
3487	5	p	1.017	1.100	1.050	1.033	1.050	1.000	1.233	1.213
3488	1	p	1.017	1.000	1.050	1.008	0.975	0.950	0.989	0.950
3514	-1		1.000	1.100	1.000	0.992	1.075	0.900	1.064	1.055

Table I.8 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
3515	10	g	0.983	1.050	0.983	0.992	1.050	0.900	0.959	0.968
3516	1	p	1.017	1.050	1.017	0.975	1.050	0.900	1.026	0.984
3517	-1		1.000	1.100	1.000	0.975	1.050	0.900	1.040	1.014
3627	-1		1.017	1.100	1.017	1.017	1.075	0.900	1.100	1.100
3641	14	p	1.000	1.100	1.017	1.025	1.050	0.900	1.057	1.065
3646	-1		1.017	1.100	1.017	1.017	1.075	0.900	1.100	1.100
3651	2	g	1.017	1.000	1.017	1.017	1.000	0.900	0.930	0.930
3652	2	p	1.017	1.050	1.017	1.008	1.050	0.900	1.026	1.017
3654	2	p	1.017	1.050	1.017	1.008	1.025	0.950	1.057	1.048
3655	12	p	1.017	1.100	0.983	0.983	1.050	0.900	1.039	1.039
3825	5	p	1.033	1.050	1.050	1.033	1.050	0.900	1.077	1.060
3835	8	p	0.983	1.100	1.050	1.042	1.025	0.900	1.048	1.039
3864	11	p	1.017	1.100	1.050	1.050	1.050	0.900	1.110	1.110
3865	12	p	1.017	1.100	1.050	1.033	0.975	0.900	1.030	1.014
3866	2	g	1.033	1.000	1.050	1.050	0.925	0.950	0.953	0.953
3867	23	p	1.017	1.100	1.050	1.050	1.050	0.900	1.110	1.110
3868	8	p	1.033	1.050	1.033	1.033	1.025	0.900	1.034	1.034
3872	6	p	1.000	1.050	1.050	1.033	1.025	0.900	1.017	1.001
3874	10	g	1.033	1.100	1.050	1.042	1.000	0.900	1.074	1.066
3875	-1		1.017	1.100	1.050	1.042	1.050	0.900	1.110	1.101
3882	-1		1.017	1.100	1.050	1.042	1.050	0.900	1.110	1.101
3911	-1		1.000	1.100	1.000	1.008	1.025	0.900	1.015	1.023
3913	5	p	1.017	1.050	1.017	1.017	1.025	0.950	1.057	1.057
3914	2	g	1.017	1.100	0.983	0.992	1.025	0.900	1.014	1.023
3915	-1		1.017	1.100	1.017	1.025	1.025	0.950	1.107	1.116
4025	-1		0.983	1.100	1.050	1.042	1.075	0.900	1.099	1.090
4026	-1		0.967	1.100	1.067	1.042	1.100	0.900	1.123	1.097
4149	3	p	1.017	1.000	1.050	1.042	1.025	0.900	0.985	0.977
4152	19	p	0.983	1.100	1.050	1.042	1.000	0.950	1.079	1.070
4158	12	p	1.033	1.100	1.050	1.042	1.050	0.900	1.128	1.119
4159	21	p	1.000	1.100	1.050	1.042	1.025	0.900	1.065	1.057
4162	18	p	1.033	1.100	1.050	1.042	1.025	0.950	1.162	1.153
4166	-1		1.017	1.100	1.033	1.025	1.050	1.000	1.213	1.204
4169	2	p	1.017	1.000	1.050	1.033	1.000	1.000	1.068	1.051
4171	2	g	1.033	1.050	1.050	1.025	1.025	1.000	1.168	1.140
4172	-1		1.017	1.100	1.050	1.050	1.025	1.000	1.204	1.204
4173	-1		1.033	1.100	1.050	1.033	1.075	1.000	1.283	1.263
4178	3	p	1.017	1.050	1.050	1.042	1.050	0.900	1.059	1.051
4279	-1		1.017	1.100	1.033	1.025	1.100	0.900	1.144	1.135
4286	4	p	1.033	1.100	1.033	1.017	1.075	0.950	1.200	1.180
4287	3	p	1.033	1.100	1.033	1.017	1.050	0.950	1.172	1.153
4413	2	p	0.967	1.050	1.050	1.025	1.075	0.900	1.031	1.007
4416	18	p	1.000	1.100	1.050	1.033	1.075	0.900	1.117	1.100
4417	8	g	1.000	1.100	1.050	1.033	1.100	0.900	1.143	1.125
4418	-1		0.967	1.100	1.033	1.017	1.075	0.900	1.063	1.046
4635	-1		1.017	1.100	1.017	1.017	1.050	0.900	1.074	1.074
4643	-1		1.017	1.050	1.017	1.017	1.025	0.900	1.001	1.001
4645	-1		1.033	1.100	1.033	1.017	1.075	0.900	1.136	1.118
4650	4	p	1.017	1.050	1.017	1.008	1.075	0.900	1.050	1.041
4654	-1		1.017	1.100	1.017	1.025	1.100	0.900	1.126	1.135
4724	14	p	1.000	1.100	1.050	1.033	1.075	0.900	1.117	1.100
4732	2	p	1.000	1.100	1.067	1.033	1.050	0.900	1.109	1.074
4735	-1		0.983	1.100	1.050	1.033	1.025	0.900	1.048	1.031
4738	-1		0.967	1.050	1.067	1.025	1.050	0.900	1.023	0.983
4739	-1		0.967	1.100	1.050	1.033	1.050	0.900	1.055	1.038
4801	2	p	1.033	0.950	1.033	1.017	1.000	0.900	0.913	0.898
4802	3	p	1.033	0.950	1.033	1.017	1.000	0.900	0.913	0.898
4803	9	g	1.033	1.100	1.050	1.033	1.050	0.950	1.191	1.172
4921	5	p	1.017	1.050	1.050	1.050	1.050	0.900	1.059	1.059
4925	-1		1.017	1.100	1.050	1.042	1.050	0.900	1.110	1.101
4933	-1		1.033	1.050	1.067	1.042	1.050	0.900	1.094	1.068
4940	1	g	1.033	1.050	1.050	1.050	1.025	0.900	1.051	1.051
6155	9	p	1.033	0.950	1.050	1.042	1.025	1.000	1.057	1.048
6159	3	p	1.033	1.100	1.050	1.050	1.025	0.900	1.101	1.101
6160	2	p	1.033	1.000	1.050	1.033	1.050	0.950	1.082	1.065
6161	-1		1.033	1.100	1.050	1.033	1.050	0.900	1.128	1.110
6168	3	p	1.017	1.000	1.050	1.050	1.000	1.000	1.068	1.068
6172	9	p	1.017	1.050	1.050	1.042	1.075	1.000	1.205	1.195

Table I.8 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
6173	4	g	1.017	1.100	1.050	1.050	1.075	0.900	1.136	1.136
6174	4	g	1.017	1.050	1.050	1.033	1.000	1.000	1.121	1.103
6176	4	g	1.017	1.100	1.050	1.033	1.100	1.000	1.292	1.271
6220	33	g	1.000	1.100	1.033	1.017	1.050	1.000	1.194	1.174
6225	20	p	1.017	1.100	1.050	1.025	1.050	0.950	1.171	1.143
6313	9	p	1.033	1.100	0.967	0.967	1.000	0.900	0.989	0.989
6321	1	p	1.017	0.950	0.967	0.983	0.975	1.050	0.956	0.972
6322	-1		1.017	1.100	0.950	0.958	1.025	0.950	1.035	1.044
6335	5	g	1.000	1.050	0.967	0.975	1.025	0.900	0.936	0.944
6339	13	p	1.017	1.100	0.950	0.967	1.000	0.950	1.009	1.027
6341	5	p	1.000	1.050	0.950	0.975	1.000	0.950	0.948	0.973
6343	4	p	1.000	1.100	0.950	0.958	1.000	0.950	0.993	1.001
6350	7	p	1.017	1.050	0.950	0.983	1.025	1.050	1.091	1.130
6351	2	p	1.000	1.050	0.983	0.975	1.025	0.900	0.952	0.944
6363	5	p	1.017	1.050	0.967	0.975	1.050	0.900	0.975	0.984
6364	11	g	1.017	1.050	0.967	0.975	1.050	0.950	1.029	1.038
6367	6	g	1.000	1.100	0.950	0.975	1.025	0.900	0.964	0.989
6369	9	p	1.000	1.100	0.983	0.983	1.025	0.900	0.998	0.998
6371	-1		1.017	1.050	0.950	0.975	1.025	1.000	1.039	1.067
6372	2	g	1.017	1.100	0.950	0.958	1.025	1.000	1.089	1.099
6373	13	p	1.017	1.100	0.950	0.958	1.050	0.900	1.004	1.013
6374	-1		1.017	1.100	0.967	0.975	1.050	0.900	1.022	1.030
6375	20	p	1.017	1.100	0.950	0.983	1.025	0.900	0.980	1.014
6376	8	p	1.017	1.100	0.950	0.975	0.975	0.950	0.984	1.010
6377	14	g	1.033	1.100	0.983	0.992	1.000	0.900	1.006	1.014
6378	-1		1.000	1.100	0.950	0.958	1.050	1.000	1.097	1.107
6379	0	p	1.000	1.050	0.950	0.967	1.025	1.050	1.074	1.092
6380	-1		1.017	1.100	0.967	0.983	1.075	0.900	1.046	1.064
6517	8	p	1.017	1.100	1.000	1.008	1.050	0.950	1.116	1.125
6538	11	p	1.017	1.050	0.983	1.000	1.000	0.900	0.945	0.961
6555	5	g	1.017	1.100	0.983	1.000	1.025	0.900	1.014	1.032
6556	6	p	0.983	1.100	0.983	1.008	1.025	0.900	0.981	1.006
6559	1	p	1.017	1.000	0.983	0.992	1.025	0.950	0.973	0.982
6561	3	p	1.000	1.050	0.983	1.000	1.025	0.950	1.005	1.022
6563	1	p	1.017	1.050	0.983	1.000	1.000	0.900	0.945	0.961
6567	6	p	1.017	1.050	0.983	0.983	0.950	0.900	0.898	0.898
6570	3	g	1.000	1.050	0.983	1.000	0.975	0.900	0.906	0.921
6574	8	p	1.017	1.100	1.000	1.008	1.025	0.900	1.032	1.040
6577	28	p	1.017	1.100	0.967	1.000	1.025	0.950	1.053	1.089
6578	9	g	1.000	1.100	0.983	1.000	1.025	0.950	1.053	1.071
6580	13	p	1.017	1.100	0.983	1.008	1.075	0.900	1.064	1.091
6581	13	p	1.017	1.100	0.983	1.000	1.025	0.900	1.014	1.032
6585	2	p	1.017	1.000	0.983	1.008	0.975	1.000	0.975	1.000
6587	7	p	1.017	1.050	1.000	1.017	1.025	0.950	1.039	1.057
6588	3	p	1.017	1.100	0.983	0.992	1.050	0.900	1.039	1.048
6589	2	p	1.033	1.100	0.983	1.008	1.050	0.950	1.115	1.143
6806	-1		1.017	1.100	0.983	0.992	1.100	0.900	1.089	1.098
6807	12	p	1.017	1.100	1.000	1.008	1.050	0.900	1.057	1.066
6814	2	p	1.017	1.000	0.983	0.992	1.000	1.000	1.000	1.008
6816	-1		1.017	1.100	0.983	1.000	1.050	1.050	1.212	1.233
6817	-1		1.017	1.100	0.983	1.008	1.000	1.050	1.155	1.184
6819	-1		1.017	1.100	0.983	0.983	1.050	0.900	1.039	1.039
6820	-1		1.017	1.100	1.000	1.008	1.050	0.900	1.057	1.066
6918	-1		1.017	1.100	1.000	1.008	1.075	0.900	1.082	1.091
6951	-1		1.017	1.100	0.967	0.983	1.075	0.900	1.046	1.064
6954	2	g	1.017	1.050	1.050	1.042	1.025	0.900	1.034	1.026
6959	-1		1.017	1.100	0.967	0.975	1.100	0.900	1.070	1.079
8413	-1		1.017	1.100	1.000	1.008	1.075	0.900	1.082	1.091
8418	4	p	1.017	1.050	0.983	0.992	1.025	1.000	1.076	1.085
8419	1	p	1.017	1.100	0.983	0.983	1.050	0.900	1.039	1.039
8429	2	p	1.017	1.000	1.033	1.025	1.025	0.900	0.969	0.961
8431	-1		1.017	1.100	1.050	1.042	1.050	0.900	1.110	1.101
8437	-1		1.017	1.000	0.983	1.000	1.025	0.900	0.922	0.938
8438	-1		1.017	1.100	0.983	0.992	1.050	1.000	1.155	1.164
8439	-1		1.017	1.050	0.983	0.992	1.025	0.900	0.968	0.977
8444	-1		1.017	1.100	0.950	0.967	1.050	1.100	1.227	1.249
8446	-1		1.017	1.100	0.983	1.000	1.050	0.900	1.039	1.057
8447	-1		1.017	1.100	0.950	0.975	1.075	0.900	1.028	1.055

Table I.8 (Continued)

Store ID	First leaks	Types	Factor A	Factor C	Factor E	Factor E1	Factor F	Factor G	ESL	ESL+ extra
8454	-1		1.017	1.100	0.983	0.992	1.050	0.900	1.039	1.048
8469	1	p	1.017	0.950	1.000	1.017	1.000	1.050	1.014	1.031
8518	-1		1.017	1.100	0.983	1.000	1.050	0.900	1.039	1.057
8519	-1		1.017	1.100	0.967	1.000	1.075	0.900	1.046	1.082
8520	-1		1.000	1.100	0.983	0.983	1.050	0.900	1.022	1.022
8521	-1		1.017	1.100	0.983	1.008	1.075	1.050	1.241	1.273
8523	-1		0.983	1.100	0.983	0.992	1.075	0.900	1.029	1.038
8527	-1		1.017	1.100	1.000	0.992	1.100	0.900	1.107	1.098
8531	4	p	1.017	1.100	0.983	0.992	1.050	0.900	1.039	1.048
8537	8	p	1.017	1.050	0.983	1.000	1.025	0.950	1.022	1.039
8539	-1		1.017	1.100	1.017	1.008	1.075	0.900	1.100	1.091
8540	1	p	1.017	1.000	0.983	1.000	0.975	0.950	0.926	0.942
8545	-1		1.017	1.100	0.950	0.967	1.100	0.900	1.052	1.070
8550	1	g	1.017	1.050	1.033	1.042	1.050	0.900	1.042	1.051
8561	-1		0.967	1.100	1.017	1.033	1.050	0.900	1.022	1.038
8563	-1		0.967	1.100	1.017	1.025	1.100	0.900	1.070	1.079
8577	-1		1.017	1.100	1.000	1.017	1.075	0.900	1.082	1.100
8583	-1		0.967	1.100	1.050	1.033	1.100	0.900	1.105	1.088
8598	-1		1.017	1.100	1.050	1.033	1.050	0.900	1.110	1.092
8913	2	p	1.017	1.050	1.017	1.000	1.025	0.900	1.001	0.985
8916	1	g	1.033	1.050	1.000	1.000	1.050	0.900	1.025	1.025
8918	-1		1.017	1.100	1.050	1.025	1.050	0.900	1.110	1.083
8919	-1		1.017	1.100	1.000	1.008	1.075	0.950	1.142	1.152
8922	10	p	1.017	1.100	1.017	1.025	1.025	0.950	1.107	1.116
8924	7	p	1.017	1.050	1.000	1.008	1.025	0.900	0.985	0.993
8926	-1		1.017	1.100	0.950	0.983	1.050	0.900	1.004	1.039
8929	5	p	1.017	1.050	0.967	1.000	1.050	0.950	1.029	1.065
8931	12	p	1.017	1.100	1.050	1.025	1.050	0.950	1.171	1.143
8941	-1		1.000	1.100	1.050	1.033	1.075	0.900	1.117	1.100
8951	-1		1.017	1.100	0.983	1.000	1.075	0.950	1.123	1.142
8955	-1		1.017	1.100	1.033	1.025	1.075	0.900	1.118	1.109
8964	-1		0.983	1.100	1.033	1.017	1.075	0.900	1.081	1.064
8966	-1		0.967	1.100	1.067	1.033	1.100	0.900	1.123	1.088
8976	-1		1.017	1.100	0.983	1.000	1.075	0.900	1.064	1.082
8984	-1		1.017	1.100	1.017	1.017	1.000	0.900	1.023	1.023
8994	7	p	1.017	1.100	1.017	1.017	1.025	0.900	1.049	1.049
8996	-1		1.017	1.100	1.050	1.050	1.100	0.900	1.163	1.163
8998	-1		1.000	1.100	1.017	0.983	1.075	0.900	1.082	1.047

Note: -1 represent no leaks

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